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MANPOWER/HARDWARE LIFE CYCLE COST ANALYSIS STUDY.(U)
NOV 79 F Y YORK, R A BUTLER, H L ESKEW N00014-77-C-0809

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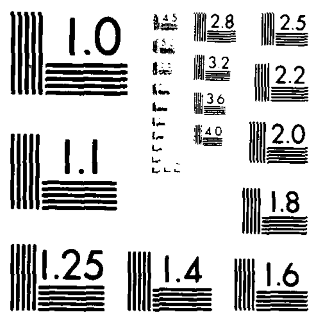

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MANPOWER / HARDWARE LIFE CYCLE COST ANALYSIS STUDY

UNITED STATES NAVY
CHIEF OF NAVAL OPERATIONS

FINAL REPORT

6 NOV. 1979

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER HM-79112C	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
(6) 4. TITLE (and Subtitle) Manpower/Hardware Life Cycle Cost Analysis Study		5. TYPE OF REPORT & PERIOD COVERED Study (10/77-12/78)
		6. PERFORMING ORG. REPORT NUMBER
(10) 7. AUTHOR(s) LT Francine F. York USN Mr. Robert A. Butler (The Assessment Group) Mr. Henry L. Eskew (ASC)		(15) 8. CONTRACT OR GRANT NUMBER(s) N00014-77-C-0809 new and ~~N00014-77-C-0811~~
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of the CNO (OP-01) Navy Department Washington, D.C. 20350		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office of the CNO (OP-96) Navy Department Washington, D.C. 20350		(11) 12. REPORT DATE 6 Nov[illegible]79
		13. NUMBER OF PAGES 480
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (14) AG-HM-79112C		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(12) 495

DTIC ELECTE MAR 6 1980 C

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(9) Rept. for Oct 77-Dec 78

18. SUPPLEMENTARY NOTES

Prepared in cooperation with:

The Assessment Group
710 Wilshire Blvd. - Suite 301
Santa Monica, CA. 90401

Administrative Sciences Corp.
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Alexandria, VA. 22304

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Life Cycle Cost (LCC)
Navy Manpower
Cost Analysis
Cost Models
Manpower, Personnel, Training (MPT)
Manpower/Hardware
Billet Cost Model

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Manpower/Hardware Life Cycle Cost (LCC) Analysis Study was conducted to analyze life cycle cost models and methods, with particular emphasis on Manpower, Personnel and Training Support (MP&TS) costs, and their contribution to total system economic costs over the life cycle of a weapon system. The study's principal objective was to examine the Weapon System Acquisition Process (WSAP) to determine when manpower/hardware tradeoffs should be made, the level of detail necessary, and specifications for the MP&TS LCC model

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S/N 0102-LF-014-6601

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necessary to perform the analysis. Existing Navy MP&TS cost models are examined to determine their ability to accurately reflect the economic cost of military manpower relevant for tradeoff decisions. Several hardware costing techniques are also reviewed to determine their usefulness for conducting hardware/manpower cost tradeoff analyses. The report makes specific recommendations and proposes guidelines for the development of cost models and techniques that facilitate hardware/manpower tradeoff analysis.

DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON, D.C. 20350

IN REPLY REFER TO
Ser 96/193221

NOV 6 1979

From: Chief of Naval Operations

Subj: Manpower/Hardware Life Cycle Cost (LCC) Analysis Study Report; promulgation of

Encl: (1) Manpower/Hardware LCC Analysis Study Report

1. The Manpower/Hardware LCC Analysis Study was initiated to analyze current Navy efforts in the determination of LCC elements necessary to make manpower/hardware tradeoffs and to analyze and develop requirements and recommendations for an existing, modified, or new LCC model to be used to perform those functions during the Weapon System Acquisition Process (WSAP).

2. The study report forwarded as enclosure (1) is divided into three parts:

a. Part I (Task I of the Study) presents a conceptual overview of the WSAP and provides a skeletal process by which the hardware/manpower tradeoff analysis must be integrated into the WSAP.

b. Part II (Task II) discusses the economics of hardware manpower cost analysis, presents a critical review of a few Navy hardware cost models and provides a set of broad guidelines for the merger of manpower cost considerations with hardware cost methods.

c. Part III (Task III) critically reviews Navy manpower cost models and provides recommended changes to the Navy Billet Cost Model (BCM) which will improve the accuracy of manpower cost estimates.

3. The study was unable to complete Task IV specified in the study directive, i.e., the formulation of specifications for a model or set of models with which to conduct manpower/hardware LCC tradeoff analysis. The complexity of such an undertaking proved beyond the scope of this effort. As a result, the study Advisory Committee and other Navy reviewers have recommended that additional research be conducted to determine user requirements, methods, and data availability before model specifications are formulated.

Ser 96/193221

Subj: Manpower/Hardware Life Cycle Cost (LCC) Analysis Report; promulgation of

4. This follow-on research will be conducted through the HARDMAN Office (OP-112C) and the responsibility for directing these efforts will shift to the HARDMAN Flag Officer Steering Group.

M. S. HOLCOMB
Vice Admiral, U.S. Navy
Director, Navy Program Planning

Distribution:
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Ser 96/193221

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INTRODUCTORY NOTE

This final report on the Manpower/Hardware Life Cycle Cost (LCC) Analysis Study is based on the compilation of three distinct task reports. Part I of the report was prepared by the study project officer. Part II is the product of The Assessment Group of Santa Monica, CA., and Part III was prepared by Administrative Sciences Corporation of Alexandria, VA.

The page numbering system for each task report has been left intact, and each has a separate table of contents, list of figures and tables, appendices, etc. The table of contents and executive summary are intended only to highlight the study tasks for the reader.

CONTENTS

EXECUTIVE SUMMARY

A. BACKGROUND

The Department of Defense has structured a process to be followed in the acquisition of major weapon systems. A central criterion in the choice of alternative weapon systems is the total cost of the system over its economic life, i.e., its life cycle cost. The cost of operating and maintaining (as opposed to procuring) the weapon system will largely be determined by the quantity and skill mix of manpower required for the successful performance of these functions over the life cycle of the system.

The recent dramatic increase in Manpower, Personnel, and Training Support (MP&TS) costs has illuminated the fact that more attention should be given (and given earlier) in the Weapon System Acquisition Process (WSAP) to identification of the manpower requirements and the associated MP&TS costs of new technology weapon systems. The proliferation of life cycle cost models within the Navy, and of alternative philosophies and methodologies in computing MP&TS costs, have made it difficult to determine which model or methodology is applicable to the derivation of cost-effective manpower tradeoffs in the WSAP.

As a result of the concern in this area, the Manpower/Hardware Life Cycle Cost Analysis Study was established as part of the Chief of Naval Operations (CNO) Studies and

Analysis Program (CSTAP) for FY-77. Its purpose was to conduct a critical examination of life cycle cost models and methodologies, with particular attention to MP&TS costs, and their contribution to total system economic costs over the life cycle.

This final report, prepared with contractor support of The Assessment Group and Administrative Sciences Corporation, presents the findings and recommendations of the study.

B. PURPOSE OF THE STUDY

The CNO directed the Manpower/Hardware LCC Analysis Study to perform four tasks:

TASK	PURPOSE
1	Develop a conceptual overview of the WSAP as a series of economic decisions and determine the appropriate scope of manpower/hardware tradeoff analysis within the WSAP.
2	Analyze the WSAP to determine the points or stages at which manpower/hardware tradeoffs should be made, the level of detail applicable to each point, the organization that should conduct the analysis at each point and specifications for the MP&TS LCC model necessary to perform the analysis.

3 Analyze and evaluate existing Navy MP&TS cost models to determine their ability to accurately reflect the economic cost of military manpower relevant for making manpower/hardware tradeoff decisions within the WSAP.

4 Integrate the results of Tasks 1 through 3 into a coherent plan which provides the specifications for the analytic framework from which to conduct manpower/hardware tradeoff analysis during the WSAP.

C. FINDINGS

As a result of the analysis, the Manpower/Hardware LCC Study found that:

- Any acceptable cost tradeoff system must:
  - offer rapid turn-around time for cost analysis at low cost.
  - be effective early in the design process when the majority of ultimate life cycle costs are fixed.
  - deal with costs on a mathematically consistent basis throughout the design process.
  - be able to exploit the increasingly detailed information that becomes available as a design matures.

- offer a method of cost communication between designers working on separate elements of the system and between designers and support specialists.

- consider all manpower costs and estimate them correctly.

- Cost methods must be capable of portraying alternative design approaches and must also be capable of estimating the relative factor prices of hardware and labor accurately.

- Parametric methods are most useful in the estimation of acquisition costs in the earliest stages of the weapon system acquisition process.

- Of the several hardware life cycle cost models reviewed, none were found to be useful (as presently configured) for conducting hardware/manpower cost tradeoff analysis:

  - only one model was intended for use in the conceptual phase of the WSAP.

  - all the other models are chiefly useful only after a relatively detailed design has been achieved.

- The concept of a "billet cost model" is sound and the need for such a model is undeniable.

- The present Billet Cost Model contains deficiencies related to input data and lack of thorough and timely documentation. Remedies for these deficiencies are fairly straightforward.

- Other sources of Navy manpower costs, i.e., Composite Standard Rates, the Navy Resource Model, and OASD (Comptroller) reports are generally deficient for use where manpower requirements are defined in less detail than rating and grade. Deficiencies include:

  - omitted or improperly treated cost elements, especially training and retirement costs.

  - inability of the sources to differentiate between occupational categories and/or skill levels of manpower.

- The formulation of specifications for a model or set of models with which to conduct manpower/hardware LCC tradeoff analysis (Task 4) is premature and beyond the scope of this effort.

D. RECOMMENDATIONS

The following is a summary of the Manpower/Hardware LCC Analysis Study recommendations:

- For operating and support costs (and therefore life cycle costs) a different approach called process modeling is more appropriate.

- A cost tradeoff system, called a linked and graded model system, may be the appropriate resolution. This system consists of three elements:

- a system slide rule model used by the senior designer during the earliest stages of system design to aid in the determination of initial configuration.

- a slide rule aggregation model, consisting of slide rule models at three levels of aggregation: component, subsystem, and system. These indenture levels are linked through a common input/output medium. The output from models at each level of aggregation are used as data for the next higher indenture level models.

- a full scale cost model implemented on a production computer. The model is similar to the slide rule aggregation model system but is capable of more sophisticated cost analysis.

Generally, the system slide rule model would be used during the Conceptual Phase of the Weapon System Acquisition Process, the slide rule aggregation model system during the earlier phases of the Validation Stage and the full scale model during the latter stages of Validation and the earlier stages of Full Scale Development.

- The approach to hardware/manpower cost analysis should be based on the economic costs involved.

- Specific recommendations for remedying the technical problems noted in the Billet Cost Model are contained in Part III.

- The CNO (OP-01) should publish, on an official and annual basis, a Billet Cost Report consisting of:

  - a text which thoroughly explains how the estimates were developed and which estimates are appropriate for different uses.

  - two sets of marginal cost estimates: one by rating and grade and the other generalized across ratings and grades.

  - a final section consisting of average cost estimates of which there would also be two sets. These would be applicable to decision analysis involving large increments or decrements of manpower.

Throughout the report, all non-Navy costs should be made sufficiently visible so that total billet costs, the net of those amounts, would be readily available for use in analyses which are administratively constrained to include only Navy funded costs. The overall goal of the report would be to serve a very broad spectrum of manpower costing needs throughout the Navy and to insure that no set of needs is sacrificed or compromised in order to satisfy another.

- Before manpower/hardware LCC tradeoff analysis model specifications are formulated, additional research should be conducted to determine user requirements, methods and data availability.

MANPOWER/HARDWARE LIFE CYCLE

COST ANALYSIS STUDY

TASK 1 REPORT

OF

MARCH 1979

MANPOWER/HARDWARE-LIFE CYCLE COST ANALYSIS STUDY

Task-1 Report

I. BACKGROUND

Probably the best measure of the nation's priorities is the federal budget. The administration's judgements about the proper allocation of public resources lead to budget decisions that profoundly affect the Department of Defense.

The portion of the federal budget allocated to defense has changed markedly over the past two decades. In the mid-1950's national defense outlays represented approximately 58 percent of total federal outlays. By the mid-1960's, despite the Vietnam War, outlays for defense had declined to considerably less than one-half of total outlays (43 percent in FY 1966); by 1976 defense spending accounted for only about one-fourth of the federal budget.

There have been, however, two more serious trends than this proportional decline in spending. Firstly, from 1968 through 1976 there was an actual reduction in real defense spending (that is spending corrected for inflation to show actual purchasing power). In FY 1975, real defense spending was decreased by some $7 billion because of unanticipated price increases. During this period, moreover, manpower and manpower-related costs have risen dramatically, both in absolute terms and as a proportion of the defense budget. The end result is that spending for supplies and military equipment was even more sharply curtailed.

Secondly, while U.S. defense spending was declining, the military capability of the Soviet Union was rapidly improving. Since many consider the military balance between the United States and the Soviet Union to be the best available yardstick for measuring the sufficiency of U.S.

defense forces, this trend has been especially disturbing. Quantitative comparisons of U.S. and Soviet capabilities, for example, have shown substantial shifts in favor of the Soviet Union.

Primarily because of the growth in the Soviet Union military capability, the Ford and Carter administrations in their budgets proposed real increases in defense spending. However, these increases were relatively small and devoted primarily to the procurement of military hardware. Manpower and manpower-related costs have been a different matter.

Manpower cost continues to grow and has more than tripled since 1956. Additionally, DOD outlays for manpower costs have risen from $24 billion in the last pre-Vietnam year, FY 1964 to $68 billion in the President's budget for FY 1980.

Although the proportionate share of the DOD budget devoted to manpower has fallen since 1974, the fiscal 1980 percentage is still substantially above the percentage experienced during the 1950's and 1960's. Moreover, the fall in the percentage of the defense budget devoted to manpower since fiscal 1974 has not been the result of falling manpower costs, though limitations on military and civilian personnel pay increases since fiscal 1975 helped to hold down the amount of increase in manpower costs. Rather, the decrease in the manpower percentage is attributable to substantial increases in other elements of the defense budget.

In addition to the magnitude of manpower costs, the composition of these budget costs has also changed considerably over the past 20 years. While the proportions of total manpower costs associated with the military and civilian components have remained roughly constant at 70 percent military and 30 percent civilian (excluding contract-hire

and support costs), the makeup of military personnel costs has shifted substantially. For example, the direct costs associated with active duty military personnel decreased from nearly two-thirds of the total manpower costs in fiscal 1956 to less than half by fiscal 1976. Budget expenditures for military retirement, on the other hand, increased from less than $500 million in fiscal 1956 to about $9.1 billion in fiscal 1978. Stated differently, military retirement costs made up less than 3 percent of manpower costs in 1956, as compared to more than 16 percent in fiscal 1978. Thus, whereas active duty personnel costs have doubled in the past 20 years, the "peripheral" elements, including reserve personnel, retired personnel and family housing costs, were nearly 15 times as large in fiscal 1976 as they were in fiscal 1956.

The main reasons manpower costs have increased so dramatically over the last couple of decades while the number of active military and civilian personnel have actually decreased are:

- Civilian pay has gone up under the present adjustment process;
- Military pay has risen since the passage of Public Law 90-207 in 1967, linking military pay increases to Federal Civilian pay increases;
- Civilian and military retired pay rose as a result of the increases in active duty pay and cost-of-living adjustments; and
- The number of military and civilian retirees has increased (due to the military retirement reform immediately following World War II, instituting the 20-year retirement policy, and the build up of forces during the Korean War).

At the present time retirement pay is paid for out of the current budget and the policy planner has little or no flexibility to reduce these

outlays, since they are the result of past promises and policies. As a result, there is little incentive to institute changes which, at best, could only realize cost savings in the future.

The military personnel serving today are earning future retirement benefits. The value of these benefits is relevant in considering current defense programs and their costs. This ultimate cost of military retirement benefits earned amounts to more than $7 billion for 1979. This large cost is not shown in the budget nor elsewhere in the accounting and financial system. The ultimate costs of active military personnel are thus significantly understated at all levels: in local and headquarters manpower costs analyses, in the budget, and in the materials presented to the Congress.

Legislation is proposed to finance military retirement costs on an accrual basis. The law would require the appropriation of funds to cover accrued retirement costs in the regular military personnel appropriations, so that the true current cost would be reflected in the national defense function in the budget, along with other current defense costs. This will clear up some major problems in management and in the budgetary treatment of military retirement.

Furthermore, the Office of Managment and Budget (OMB) Circulars A-76 and A-109 require the utilization of life cycle costs in making procurement decisions on major systems. OMB Circular A-109 defines life cycle cost to mean "the sum total of the direct, indirect, recurring, nonrecurring, and other related costs incurred, or estimated to be incurred, in the design, development, production, operation, maintenance and support of a major system over its anticipated useful life span". There is also an increased emphasis on the initial phases of the system acquisition process to allow

competitive exploration of alternative system design concepts in response to mission needs. Therefore, life cycle costs must be addressed as early as possible in the acquisition process.

The decrease in defense spending and the increase in manpower costs combined with the projected decrease in available recruit propulation (manpower supply) during the next decade requires careful management planning to assess/achieve manpower supportability/affordability for current, pending, and future programs. One method is through improvements in the Weapons Systems Acquisition Process (WSAP) relative to manpower and training.

The Navy engages in a weapon systems acquisition program on a continuing basis. The purposes attached to the acquisition program include modernization, upgrading, and replacement of equipment. Navy weapon systems procurement is dominated by large systems, particularly ships and aircraft. However, there are numerous smaller systems also being acquired. The manpower and training implications, plus associated costs for acquisition of the many Navy systems (large and small) can be staggering.

There has been continuing concern on the part of Navy planners with respect to their capability to adequately anticipate as well as meet the manpower and training requirements associated with these weapons systems. Too often, explicit identification of manpower and training requirements has been excluded early in the acquisition stages to avoid exceeding thresholds for management review. The end result has been late determination of needs, with corresponding training and manning problems. Further, when systems have gone through the conceptual phase and are approved (to that point), a substantial portion of life cycle costs has already been predetermined, including costs and resource commitments

for manpower and training without full consideration of the total implications including manpower/hardware tradeoffs.

In view of these problems a study of military manpower versus hardware procurement (HARDMAN) was directed. The objectives of the HARDMAN study were to evaluate the existing manpower/training planning process associated with weapon system acquisition and develop more effective ways in which to insure early and complete consideration of the tradeoff between manpower/training requirements analysis and equipment design.

The HARDMAN Study found that:

- o Requirements for manpower planning and tradeoff analysis in the WSAP occur too late and fail to address the major issues.
- o DOD and DON directives and instructions concerning WSAP are piece-meal and fail to reflect a systematic statement of procurement policy and guidance for managers to follow.
- o Key participants in the acquisition process often lack the analytical tools for determining and insuring visibility for manpower and training requirements early in system development.

The HARDMAN Study included the following recommendations:

- o Establish a HARDMAN Project Office with the mission to insure that manpower and training analysis is conducted in a timely manner during the WSAP.
- o Develop HARDMAN capabilities to support the early idenfication and review of manpower and training requirements.
- o Implement analytical tools and review procedures supporting HARDMAN functions.
- o Implement a reporting and control system for HARDMAN functions in the WSAP.

o Develop HARDMAN improvements through revised procedures and a HARDMAN information system.

II. SCOPE OF THE CSTAP STUDY

The studies reported here represent the first elements of a development effort planned for the next three years. The ultimate objective of this effort is to develop suitable tools of cost analysis for the Weapon System Acquisition Process. The term suitable covers a variety of necessary characteristics. The tools must be:

- o reflective of the true costs of manpower
- o able to portray manpower trade-offs with other resources
- o adaptable to information available at different stages of the WSAP
- o sufficiently accurate to provide a sound decision making basis
- o integrated with other manpower, personnel and training (MPT) planning and analysis methods

To accomplish the objectives set out above, the HARDMAN Project Master Plan (PMP) includes a sequence of work elements based on the initial work reported here. The developmental effort is, like the WSAP itself, iterative in nature. At each stage of the planned project, the work of earlier stages is reexamined, problems uncovered earlier are addressed and solutions developed.

The fundamental concerns in life cycle cost (LCC) analysis break down into two areas: the cost of a man and the manpower cost implications of hardware acquisition. The first is used as an input to the second. The two studies reported here deal with these two issues. It should be noted, however, that the first area of concern - the cost of a man - has been the subject of scrutiny in the Navy for a considerable period, while the second concern is relatively new. As a consequence, subsequent effort in the HARDMAN PMP is focused entirely on the manpower cost implications

of hardware acquisition. We refer to this concern as HARDMAN LCC analysis.

The HARDMAN PMP calls for a battery of studies leading up to the specification and implementation of a sequence of LCC tools which can either be used as they are developed or for more specific models. The initial studies are intended to do, in much greater detail, what was done and reported in Task II of this report. Three work packages are isolated:

- o A summary of available data for LCC analysis
- o A summary of existing methods
- o A summary of user requirements

Each of these studies is structured by reference to the results of the Task II study. Their results, in addition to work accomplished in other areas of the HARDMAN Project, form the basis for the development of the specifications, mentioned earlier. After these preliminary developments, the HARDMAN LCC effort moves into its implementation phase. This phase consists of model development, pilot project testing, revision and finalization effort for four classes of models: ACAT I and II Ship, Air and Other, and ACAT III and IV. The category "Other" includes, submarine, space, land-based and multi-environment models.

For each of the four classes, preliminary model systems will be built according to the general specifications developed on the basis of research studies. The general models will be adapted to the specific needs of a pilot program and used in connection with that program for at least a period of one year and at most until the Full Scale Development Phase is underway. Lessons learned during the pilot program will be incorporated into the general model, user documentation finalized and the entire package of models and documentation published for use by appropriate Navy Program officers.

As new lessons are learned with each subsequent class of model systems, they will be incorporated as changes to the previous models. The program plan is also structured to take advantage of the learning process: the simplest model system is developed first and each subsequent task engenders more difficulty. Air systems are more difficult to model than surface ship systems, and the third class includes three complete model systems (subsurface, space and land) in addition to the multi-environment system. The fourth class of models include extracting sub-system models for every environment from the work accomplished in the first three ACAT I and II classes.

The end result will be a library of cost tools satisfying the criteria set out at the beginning of this section. A program office, responsible for any kind of Navy hardware acquisition will be able to obtain a system of working models with complete documentation, capable of supplying LCC analysis and information from program inception through Full Scale Production. The models will not only be accurate and easy to use, but reflective of the long term costs to the Navy of current decisions. Finally, they will incorporate MPT planning principals and generate planning information from the earliest stages of the WSAP.

As noted above, the CSTAP has contributed two fundamental studies to the HARDMAN LCC effort outlined above. The first of these, Task III, applies to the costs of a man and the second, Task II, applies to the manpower cost implications of hardware acquisition. The scope of these two efforts is discussed briefly below.

The Navy has available to it a variety of models intended to estimate the cost of individual men. These models vary in their degree of detail as well as purpose and underlying premises. The most important,

most accurate and most appropriate of these is the Billet Cost Model. It has received a correspondingly large portion of attention in the Task III study. The purpose of that study was to determine what areas, if any, of the model's methodology or outputs should be altered, either to improve its conceptual accuracy or its utility to the Navy. The results of that study are given below as the Task III report

While there are several models available for estimating the cost of a man, there are literally hundreds of life cycle cost and operating and support cost models being used by various branches of the Navy. Despite this profusion of models, most of them follow a few basic forms and adhere to only two or three basic methodological structures. The purpose of the Task II study was to analyse representatives of these classes in detail. The analysis had two major goals:

- To determine the adequacy of manpower costing methods
- To determine the appropriateness of the models for different stages of the WSAP

In any event, the models investigated proved generally inadequate in both areas, so the study extended to the recommendation of guidelines for the incorporation of Hardware/Manpower cost analysis methods in future LCC modeling efforts. These guidelines and the model review, as well as a discussion of the theortical principals involved, are contained in the final report of the Task II effort.

III. ECONOMIC ISSUES IN CAPITAL/LABOR TRADE OFF

The production of any goods entails the transformation of inputs into outputs. The transformation occurs in the process, in a manner predicted by the production function. In turn, the production function is a type of recipe, stipulating the needed ingredients (inputs) to produce the desired output.

For simplicity, assume that only two inputs - capital and labor - are used in the production of output X. Further assume that the production function is such that it allows capital to be sustituted for labor and vice-versa. This last assumption is important, since some production techniques rely on a fixed relation of capital to labor. Consider, for example, the output of mowing a yard. In this case one person is needed for each lawnmower. Increasing the number of lawnmowers without increasing people would not result in increased output. This type of production function is known as a fixed coefficient production function and is not integral to our discussion.

In the HARDMAN System Acquisition Process the desired output is usually stated in terms of a specific operational capability required to counter a well-defined threat. The statement of this output appears in the Mission Essential Needs Statement and thus establishes the goal for the system under development. The provisions of OMB Circular A-109 are designed to preclude the acquisition of capital solely on the grounds of exploiting new technology wherein the system is acquired regardless of the labor required to support it. By closely defining the ultimate output required of the system (operational capability) it is then incumbent on the managers of the WSAP to take full advantage of a broad range of available technologies representing the capital side of the trade off

equation. These capital alternatives can then be traded off against labor to achieve the objective output in the most cost effective, feasible combination.

In a production function allowing substitution of capital for labor, the driving force behind substitution is the relationship of the price of capital to the price of labor. The price of labor is represented by the wage rate and theoretically is set equal to the extra gain in total revenue resulting from an extra addition of one unit of labor. The price of capital is assumed to be represented by the rental cost of that capital, and theoretically equals the extra contribution to total revenue accruing from an extra unit of capital. In the case of the military, revenue is not generated and some other measure of effectiveness must be used.

As the price of labor rises, vis-a-vis the price of capital, less labor and more capital should be employed, while the same level of output is produced. Substitution of capital and labor, it should be emphasized, occurs as output levels are held constant. On the other hand, if capital is increased, while the amount of labor is not reduced, output will increase. Therefore, when talking about the substitutability of capital for labor, it should be in the context of constant output levels.

In order to maximize output (or minimize costs) it can be shown mathematically that a firm should allocate its resources in such a way so that for each resource, the ratio of resource contribution to output to resource cost are all equal. In the case of two inputs, capital and labor, the inputs should be allocated so that labor's extra contribution to output divided by its cost (wage rate) equals capital's extra contribution to output divided by the cost of capital. When these ratios are equal, the firm is producing efficiently and output is maximized (or conversely, costs

minimized). If the extra contribution of labor to output divided by the wage increases relative to the similar ratio for capital, more labor should be added as you get a "bigger bang for your bucks" with labor. Capital levels should be reduced until these resources ratios are again brought into equality, and economic efficiency is achieved. A similar reaction could occur if the ratio of the change in output due to capital to its price rose relative to the similar ratio for labor. Now investing in capital yields a higher payoff, and capital is substituted for labor until the ratios are again brought into equality.

There are two reasons why the ratio of a change in output due to a change in the level of resource to its cost should increase. One is that its price falls relative to the price of other resources, which in turn induces substitution activities. The other reason is that with relative prices constant, the resource's extra contribution to output increases, again stimulating a substitution of the suddenly more productive resource for the other resources.

When making a decision on the amount of capital and labor to be employed in a project, and the project extends over a period of time, several issues must be considered in addition to the theoretical considerations discussed above. A project which extends over time introduces uncertainty, as well as questions concerning inflation and foregone earnings. An investment decision implies investing funds in a particular capital project over a period of time, in exchange for returns accruing over that investment period. Primarily because of inflation and uncertainty (risks associated with the project), a "dollar today is greater than a dollar tomorrow." This adage simply states that a given amount of returns received today is greater than that same amount received in the future.

As a result, a future return must be reduced by this combination of uncertainty (risk) and foregone earnings in order to value the returns in the present. This reduction of future funds is known as discounting and the discounted value of the funds is known as the present discounted value of the project. Future funds are discounted by a rate known as the discount rate. This rate is often approximated by the long term interest rate existing in the economy. The greater the uncertainty and risk of a project, as well as the greater the foregone earnings, the higher is the discount rate, and future earnings will have a smaller present value. Inflation rates are very difficult to predict and are usually handled by using constant dollars over the entire time period. It is this present discounted value of a project that is of importance when choosing among alternative capital projects in which to invest. The proper decision is to choose that project with the highest present value.

The choice of what rate to use as a discount rate when selecting among projects is an extremely important decision. If certain projects are less risky than others, it is necessary that returns from such projects be discounted with a smaller rate. However, utmost care must be taken in choosing a discount rate to reflect the risk of the project, as too low a discount rate will make a project appear the most profitable, when in fact, it is not.

It should be emphasized that the optimal selection of a capital project may differ over time as the discount rate changes. For example, when the discount rate is high, those projects with the greater returns accruing near the beginning of the project are more attractive than those projects with greater returns far into the future. The former type of projects will have the larger, near term returns discounted less than projects

with large, long term returns. However, as time pases, the appropriate discount rate is likely to change, and other projects may become more profitable, and switching of projects (if justified by conversion costs) may occur.

Another important consideration when comparing alternatives is the time horizon. The alternatives must be compared over the same time horizon although they may have different useful lives. For example, weapon system design A may have a life of ten years before replacement becomes cheaper than maintenance, while weapon system design B has a life of fifteen years. However, this weapon system will become technically obsolete in twenty years. In order to compare the two designs the costs should be evaluated for twenty years. That means that there will be capital expenditures at $t = 0$ and $t = 10$ for A and $t = 0$ and $t = 15$ for B (where t = the time in years). The additional life of B (ten years) is worthless because of the assumption that the weapon systems will be technically obsolete in twenty years.

Hence, when choosing among capital and labor and among various capital projects, it is necessary to consider a vast amount of information, rather than simply evaluate relative prices of capital and labor, as expressed in price economic theory. Proper evaluation of future risks, the time horizon and the choice of the discount rate as well as evaluation of initial investment cost and maintenace costs, are all essential in assessing the relative value of capital.

With respect to labor, not only the wage rate must be considered but other hidden costs and the loss of output through turnover (resulting from low wages or unstable work) are all costs integral in assessing the price of labor. Not only is the present total price of labor important, but it is necessary to also consider the future costs of labor, such as future

training and replacement costs. To analyze economic tradeoff then, the full price of labor is the relevant price and should be compared to the full cost (and returns) of capital projects.

Finally, after considering the relative full prices of labor and capital, it is essential that labor and capital be utilized in such a way so that the level of factors employed are consistent with output maximization (cost minimization). At this level of output and for given costs of resources, substitution of capital for labor cannot result in increased output without increasing costs.

IV. POTENTIAL PROBLEMS

While the CSTAP studies reported here and the HARDMAN Project in other areas have made substantial contributions to the problem of consideration of manpower cost in hardware acquisition, a number of problems remain. Three classes of problems are discussed below: institutional, early planning and resource problems.

The institutional problems are, in many respects, similar to problems typifying LCC activity in general. Most significant is the problem of generating program front end emphasis on issues that are uniquely operation and support (O&S) oriented to be first encounted at least 5-8 years in the future. The pressure of meeting near term budget and schedule constraints has tended to overshadow desireable tradeoffs of R&D or performance to reduce O&S Cost, particularly in the manpower areas.

One manifestation of the resistence to dealing with long term O&S related concerns is the preference for dealing with what are called "budget costs" instead of "economic costs". The distinction between these two cost bases is only pertinent in the short run. Because economic costs converge with budget costs if the time horizon dealt with is sufficiently long. To use a currently important example, retirement costs computed on the basis of current outstanding obligations are short term (i.e., budget cost) considerations. By the same token they are totally irrelevant to decisions concerned with the increase or reduction of manpower over the next ten to twenty years - the only kind of decision open to those engaged in weapon system acquisition.

Since the HARDMAN Project, by virture of its concern with an intrinsically long term resource, must be concerned with economic costs, it will find great difficulty in obtaining consensus for methods and policies

it devises. Nonetheless, this must be done and the weight of congressional, executive and DOD guidance and policy is solidly behind that objective. There are additional institutional problems, some mechanical that must also be recognized as not easily solved. They are:

- o Difficult to relate design tradeoffs into realistic manpower increments.
- o Difficult to relate manpower and material tradeoffs.
- o Difficult to develop relationships between manpower and skill level/capability.
- o Difficult to equate tradeoff LCC impacts into budget impacts.

The MPT planning areas offer two exceptionally difficult problems different from the institutional problems discussed above. These concern the early identification of MP&T requirements with sufficient accuracy, and the integration of costs, training and manpower planning methodologies.

With the development of increasingly sophisticated weapon systems, the Navy is faced with a similarly increasing difficulty in marshaling the resources required to support those systems at the time, in the places and in the numbers required. The most difficult part of this problem is the exceptional lead time required to develop the sophisticated manpower resources implied by complex weapon systems. Thus, early identification of training and personnel requirements in the design process is essential.

If manpower benefits are to be captured in the design process, it is generally accepted that the decision should be made early in a program. This criteria, of itself, creates problems because of

- o Lack of design detail at a level needed to describe manpower - type impacts.
- o Lack of credible definition of operational usage or system lifetime.

o Lack of insight into manpower policies, or manpower scarcity areas 5 to 10 years into the future.

New methods must be developed, adopted to the earliest stages of the acquisition process, and disseminated among those responsible for carrying out the actual work of acquisition.

In the development of new design tools and adaptation of existing ones, another problem must be confronted. This problem is the integration of planning, design, and analysis methodologies in the diverse areas of life cycle cost, manpower and training requirements determination. While each design tool might be valid by itself, it must also compliment all the other design tools in use.

Even if all the problems discussed above are confronted and the Navy as a whole resolves to find their solutions, two stumbling blocks remain: the scarcity of analytical skills to prepare the necessary decisions and the scarcity of funds in developmental programs with which to carry out the required analytical steps.

The hardware/manpower tradeoff can be credibly analyzed only when the analyst can realistically and explicitly equate technical detail into specific manpower and cost impacts.

The greatest part of the burden of analysis must necessarily fall on the shoulders of the program manager's office. This is unfortunate because that office is already so overloaded with every kind of management responsibility. Yet the forms of analysis deemed necessary are central to the program manager's single responsibility: the acquisition of a cost effective weapon system. Without these tools of analysis he cannot carry out that mission except through luck or extraordinary personal qualification and insight.

Beyond the skill itself is the need for financing both the availability and utilization of that skill. The funds made available for analysis - particularly analysis that may reveal fundamental weaknesses in concept and application - are traditionally inadequate.

Only when the development process is seen as one in which information about the true value of a new system is sequentially expanded, will adequate funds be made available to study all its characteristics - cost, MPT and performance.

AG-PR-A100-2

VOLUME I

GUIDELINES FOR HARDWARE/MANPOWER COST ANALYSIS

by

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October 1978

Contract No. N00014-77-C-0809
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Submitted to:

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Office of the Chief of Naval Operations
Department of the Navy
Washington, D.C. 20350

EXECUTIVE SUMMARY

Manpower costs are frequently the largest element in the life cycle cost of new weapon systems. In order to control these costs, it is necessary to conduct cost tradeoffs between hardware configuration and manpower requirements during the process of system design. This volume presents guidelines for constructing model systems which facilitate such tradeoffs.

Any acceptable cost tradeoff system must fulfill the following criteria: It must offer rapid turn-around time for cost analyses at low cost; it must be effective early in the design process, when the majority of ultimate life cycle costs are fixed; it must deal with costs on a mathematically consistent basis throughout the design process; it must be able to exploit the increasingly detailed information that becomes available as a design matures; it must offer a method of cost communication between designers working on separate elements of the system and between designers and support specialists; finally, all manpower costs must be covered and estimated correctly.

A cost tradeoff system, called a linked and graded model system, is seen as the resolution to the issues above. The key to the system is the concept of the slide-rule cost model. A slide-rule model is a simplified cost model, implemented on a desk-top programmable calculator, used by the designer to conduct cost tradeoff analyses. The model incorporates cost considerations into the design process, while the costing methodologies themselves can remain opaque to the user. The linked and graded model system consists of three elements: a system slide-rule model, a slide-rule aggregation model system, and a full scale aggregation model. The system slide-rule model is used by the senior designer during the earliest stages of system design to aid in the determination of initial configuration. The model considers the system as a whole by making uniformity assumptions about the nature of its subelements. The slide-rule aggregation model system builds up the system as the aggregation of lower indenture, building block elements. It consists of slide-rule models at three levels of aggregation: component, subsystem, and system. These indenture levels are linked through a common input/output medium. The output from models at each level of aggregation are used as data for the next higher indenture level models. The last model of the linked and graded system is a full scale cost model implemented on a production computer. The model is similar in structure to the slide-rule aggregation model system, but is

capable of more sophisticated cost analysis. Roughly, the system slide-rule model is used during the Conceptual Phase of the Weapon System Acquisition Process, the slide-rule aggregation model system is used during the earlier stages of the Validation Stage, and the full scale system is used during the later stages of Validation and the earlier stages of Full Scale Development.

An approach to manpower costing based on the economic costs involved in shifting personnel from different manpower pools is developed, as are the least cost algorithms for drawing from these pools. These costs include the opportunity costs of utilizing available manpower, overpayment costs which result from underutilization of skilled labor, increases in the present value of personnel due to advanced training, and other cost concepts seldom included in present manpower costing methodologies. Present methods are shown to be a special case of the more general approach developed in the guidelines. The new approach to manpower costing will require the incorporation into manpower cost analysis of some new concepts. The size of the manpower pools of available on-board, skilled and semi-skilled personnel are incorporated in the manpower costing equations, hence these values must be measured on those platforms for which a system is developed. Another new statistic, the fraction of a man's mental capacity absorbed by a system, is also suggested. The development of these statistics and their incorporation in the design process would require further research, data collection and analytic efforts for a wide variety of ship classes.

PREFACE

This volume is the first of a three-volume study on the conduct of cost trade-off analysis in which the hardware configuration and manpower requirements of a proposed weapon system offer substitution possibilities. In it, guidelines for the construction of trade-off model systems are presented. These guidelines are preceeded by a discussion of the design process highlighting the issues with which the model systems must deal.

Volume II of this report presents the theoretical economic background upon which the manpower costing methodologies are based, while Volume III reports on the results of a review of several existing Naval cost models. This review provided a touchstone for the methodologies presented in Volume I. Thus, the guidelines in Volume I are predicated on the findings of Volumes II and III.

The authors wish to acknowledge the contributions of Mr. Paul Hogan and Lt. Commander Lee Mairs, both of the Bureau of Naval Personnnel (NAVPERS 212), to this work. In addition, the mathematical abilities of Ms. Lynne Benner and the economic insights of Mr. Steven Cylke, both members of the technical staff of The Assessment Group, were invaluable in the completion of this study. All errors, omissions, and other flaws in the work are, of course, the sole responsibility of the authors.

TABLE OF CONTENTS

1.0 INTRODUCTION

The goal of this study is to present practical guidelines for the conduct of cost trade-off analyses where hardware characteristics and manpower requirements offer substitution possibilities. The guidelines cover all phases of the Weapon System Acquisition Process (WSAP). The reader will find, however, that the guidelines presented in this volume concentrate heavily on the construction of life cycle cost (LCC) trade-off analysis model systems which are intended to be used during the design phases of the WSAP.* While at first this may seem to be a narrowing of focus, in fact it is not. There are two reasons:

1. The need for guidelines is real only during the design phases of the WSAP, when the maximum number of actors are making decisions which influence cost and the decisions made have the maximum impact on the eventual total life cycle cost of the system. Decisions made during the very earliest and later stages of the WSAP are generally made by a small number of specialists. In the later stages, these specialists are already equipped with relatively good tools. In addition, the potential for cost savings during the later phases of the WSAP is small compared to the possibilities available during the design phases.

2. The problems which must be overcome to conduct cost trade-offs are such that "the system is the solution." That is, a properly constructed cost analysis model system will itself solve most of the methodological problems of trade-off analysis.

Both of these points will be discussed in detail in Chapter 2 of

*The WSAP is formally divided into four phases: Conceptual, Validation, Full-Scale Development and Production/Deployment. The first three phases are collectively referred to as the design phases in this study.

this volume.

The guidelines are not intended to be rigid specifications for the structure of the model system and the mathematical formulations of the cost equations; rather they present the general form that the model system should take, the manpower issues with which the cost models deal, and the "proper" resolutions of these issues, where the word "proper" is used to imply that result judged to be the best compromise between economic theory, cost accounting practice, information requirements, practicality, and a myriad of other factors discussed in the body of the report.

The cost formulations developed in the guidelines are strictly limited to manpower related issues (for example, the guidelines do not deal with the correct formulation of inventory stockage levels, even though it is pointed out in other parts of this report that most Navy cost models currently in use compute these values incorrectly).* However, it is important to keep in mind that the model systems are intended for conducting all types of design cost trade-offs, not merely those between hardware and manpower. It must be emphasized that the guidelines do not recommend the construction of "hardware/manpower cost trade-off models." Other cost elements must, of course, be included in the models. It is not within the scope of the guidelines, however, to include a discussion of these elements.

The guidelines, then, present the structure of a model system capable of accounting for manpower costs correctly in the context of

*See Volume III, Appendix A.

hardware cost models appropriate to different phases of the WSAP. Chapter 2 of the guidelines introduces the concept of the system, called a linked and graded model system, and connects it to the design phases of the WSAP. Chapter 3 develops the basic manpower cost equations. Chapters 4, 5 and 6, respectively, apply the concepts developed in Chapters 2 and 3 to the three design phases: Conceptual, Validation, and Full-Scale Development. Finally, some additional theoretical issues are discussed in an Appendix.

2.0 CONDUCTING HARDWARE/MANPOWER TRADE-OFFS

Any system which is intended to facilitate cost trade-off analysis during design must successfully resolve the following three issues:

1. Information feedback time
   The process of design must continue while designers wait for the results of cost analysis. The feedback loop for cost information must not be too long; otherwise the results of analysis are likely to be ignored as too much time and effort will have been committed to the already chosen design path. Further, the cost of obtaining this information must not be prohibitively high.

2. Information utilization
   Design trade-offs must be conducted early in the design process, when design alterations can still have a major effect on subsequent system life cycle costs. However, only sketchy cost information is available at this time. Cost models must be able to utilize this information, yet most existing cost models require extensive data sets to drive them - data which are not available during the early, crucial stages of design. As the design process continues, information availability and accuracy increases. It is necessary to be able to utilize this information in a manner which remains consistent throughout the design process.

3. Designer interface
   As more and more actors become involved in the design process, it becomes increasingly difficult for the actors to interface with one another. Significant system diseconomies can result unless there is a continuous, interactive flow of information between all actors involved in the design of the system.

In addition, a system useful for conducting hardware/manpower trade-off analyses must also fulfill the following criterion:

4. Manpower costing
   Manpower costs must be estimated as accurately as possible during all phases of the WSAP. Further, these costs must be driven by equipment design.

A proper appreciation of these issues is essential to the understanding of guidelines for conducting hardware/manpower trade-offs. Section 2.1 presents the background to these issues; information feedback time, information utilization, designer interface and manpower costing. Section 2.2 discusses each of them in detail. A system which successfully resolves the first three issues is presented in Section 2.3. The linkage of the system to the current weapon acquisition process is detailed in Section 2.4. The rest of the volume is devoted to the resolution of the fourth issue, manpower costing.

2.1 THE DESIGN PROCESS

The process of design can be seen as a sequence of stylized activities. First, the need for the system is understood and the general requirements of the system conceptualized. The system concept is given to a system designer, who formulates an initial technical design for a system that meets the conceptual requirements. The system is broken down into subsystems, and the subsystems further divided into components. The last are assigned to individual detail designers, who, in fact, do most of the actual design - the translation of functional requirements into physical reality. Problems or new approaches encountered in the process of detail design often require alterations in the overall system design, which are passed down as modified instructions to the detail designers. As the design process continues, various specialists (for example, reliability or maintainability specialists) add their contributions to complete the overall system architecture. This process continues up to and often beyond the production and deployment of the system, with perturbations and iterations of system design lessening with time. This process is depicted in Figure 2.1.

The ultimate configuration of the system becomes locked in as rigidity of system design increases over time, as shown in Figure 2.2.

As the figure shows, the final form (and therefore ultimate cost) of the system is almost entirely determined in the earliest stages

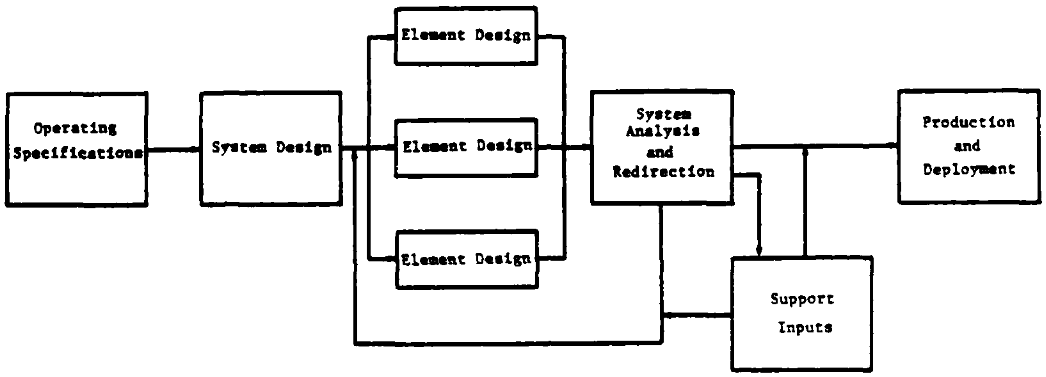

Figure 2.1 The Design Process

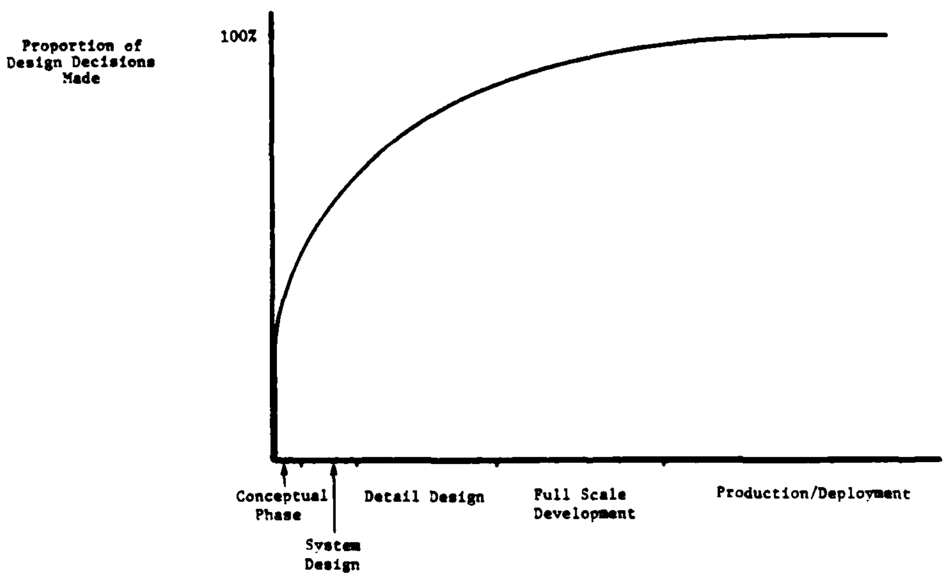

Figure 2.2 Increasing Rigidity of Design

of design. The slope of the curve in Figure 2.2 can be seen as the potential for influencing ultimate total life cycle cost by alterations in design. As Figure 2.3 shows, this potential is quite large during the early phases of design, but very quickly drops off.

The implications of the proceeding discussion are clear: efforts to reduce total costs of systems by alterations in design must be directed at the earliest stages of design.*

There is an additional point to be made, however. By using the relative number of actors involved in the design process at each step as weights, and applying these weights to the flexibility remaining in the design at that step, the resulting curve will look like Figure 2.4.

Figure 2.4 can be interpreted as follows. Conceptualization and early system design are conducted by a relatively small number of specialists whose unit impact on total life cycle cost is high. Later on, design is turned over to a large team of detail designers. While the unit cost impact of each individual designer's efforts is perhaps less than those of earlier designers, their total impact on costs is greater. Most specialists enter the picture toward the end of the design effort. Their number is small as is their potential for influencing cost. Note also that these specialists already have available to them a wide variety of fully-developed methodologies and models. The implication is that even if we could improve this area significantly, it wouldn't make much difference in total life cycle cost

*For a fuller discussion of the necessity of impact early in the design process see, " Military Manpower versus Hardware Procurement Study (HARDMAN)," Office of Chief of Naval Operations, 1977, Chap. 2.

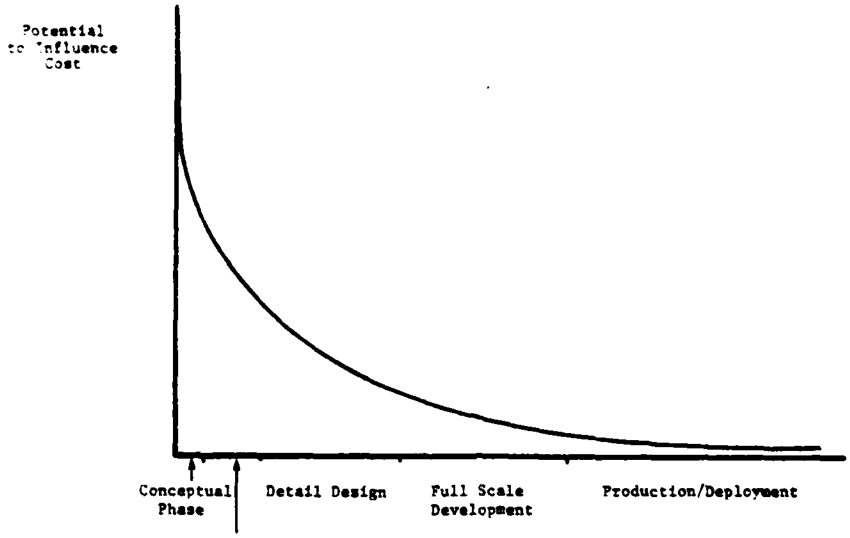

Figure 2.3 Decreasing Potential Influence on Cost

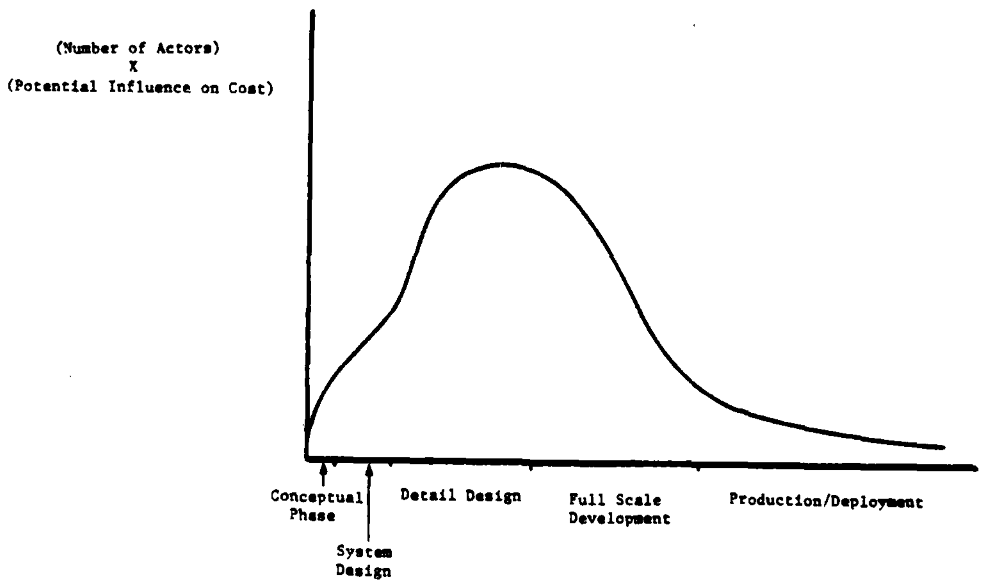

Figure 2.4 Impact on Design Weighted by the Number of Actors

compared to advances in the methods used at earlier stages.

Decisions made during the conceptual phase and the earliest parts of system design also are made by a relatively small number of specialists, each an expert in his field. Tools to facilitiate their decision processes, most in the form of parametric methods, already exist. There is some potential for their improvement (see Section 2.4). However, it is during the period of early system design that there is the greatest potential for cost savings, it is during this period that the design problems are the greatest, and it is during this period that the lack of cost trade-off decision tools is most evident.

For all the reasons above, these guidelines will concentrate most heavily on issues that arise during the system and detail design phases of the WSAP.

2.2 THE PROBLEM OF INCLUDING COST ANALYSIS IN THE CURRENT PROCESS OF DESIGN

Information Feedback Time and Information Cost*

As was indicated in the previous section, most actual design is carried out by detail designers. As the title suggests, they do not see the entire system, but only their part of it. They are generally removed, not only from the system design task, but from access to the tools employed by the systems designer to study his emerging creation. As a result, the detail designer either works in a vacuum so far as cost information is concerned, or he maintains a very formal and irregular association with those who estimate the cost impact of his efforts.

From the viewpoint of the detail designer, the feedback loop for information on the cost impact of design variation is long and costly. In the typical case, he may wait as long as two months before the system cost model produces cost estimates of his design - as well as any alternatives he had the foresight to submit for analysis. Even in the absurd best case of each designer having a cost analyst at his beck and call, he is unlikely to find this loop shorter than one or two days. The result is represented in Figure 2.5. While he waits, he must work under conditions of uncertainty about his approach

*The material for this section is adapted from Butler, Robert A., A Method for Design to Cost, RD-111, The Assessment Group, June 1977, Chapter II.

to overcoming a particular problem. He cannot stop working; he must therefore choose an alternative without benefit of the anticipated cost estimates. The cost analysis becomes, at worst, a formal exercise which is ignored. At best it signals rework or modificaton.

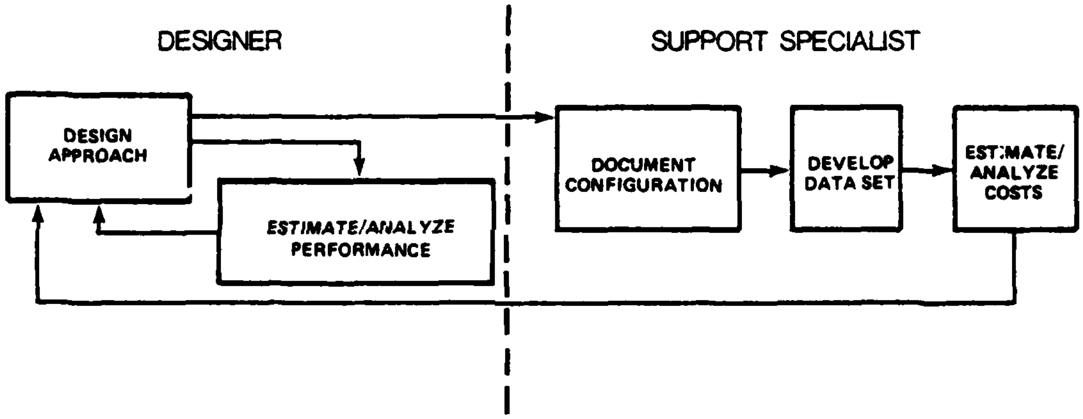

Figure 2.5 Cost Information Feedback Loop

It is almost never the case that the outcome of a cost exercise causes fundamental redesign. The reasons are simple: the engineer works under time and money constraints that make going back to the beginning almost impossible. Even with sufficient resources, it is unlikely that he would do so: undoing a conceptual structure and moving in a fundamentally new direction is extremely difficult.

The conclusion to be drawn from these arguments is that

shortening the feedback loop for information on the cost impact of alternative design approaches is critically important. As a general rule, the shorter the loop, the better - less effort is expended in a potentially wrong direction. However, beyond a certain range (counted in minutes rather than days), the lag is not important. That is, as long as the period exceeds some threshold value (undoubtedly different for each designer) the designer will try to ignore the information rather than use it. This leads us to the main problem - information cost.

For our purposes, we can think of information cost as anything - time, inconvenience, money, effort - which is interposed between a question and its answer. For an individual to be willing to pay the cost he must perceive that the benefits associated with knowing the answer at least balance the costs of obtaining it. For example, children are taught multiplication tables by rote so they can avoid the use of reference books for simple arithmetic problems; and modern economics explains the use of arbitrary rules of etiquette as a means of avoiding the information costs implied by having to constantly make trivial decisions.

An analogy to the learning of multiplications tables is the learning of rules of thumb. This has been used with design engineers for many years and the results are not encouraging. Fallacies such as the over-weening importance of high reliability (as a contributor to low life cycle cost) and low repair times have been impounded in designs, making them unnecessarily costly. The alternative is the use of cost models which handle the interplay of logistics and production variables

and react to the technical characteristics of a design. Such models exist, but as we have seen, they aren't easily accessible to the designer.

The natural solution to the feedback loop problem is to give the designer access to a personal estimating tool. Efforts to do so, however, have largely failed because they have ignored the criticality of the cost of information. The best efforts have been those which used interactive computer terminals to allow the designer to "play" with a cost model. Such terminals are expensive and scarce. Designers must queue up to use them or ask a specialist to perform analyses. In either case, the implied cost appears too great. The evidence for this is that the terminals are used only rarely, or not at all.

The appropriate conclusion to be drawn from this discussion is that anything which represents a cost or barrier to a designer in his desire to access a cost model must, if possible, be eliminated. Removal of each barrier will increase the frequency with which he will use the tool. The more often the tool is used, the better the design will be.

Information Utilization

The basic conundrum facing all design trade-off systems is this: the earlier trade-off analyses are conducted, the greater their potential for beneficial change in design, but at the same time, the earlier the state of design, the more difficult it is to obtain the data required for analysis. The result of this difficulty has been that cost analysis has been relegated to an ex poste exercise in determining what has been done, rather than helping the actual process

of design.

The conundrum exists solely due to the widespread belief that information must be of a given level of quality and quantity to be suitable for analysis. This is both true and not true. It is true that the rigor of the data and the sophistication of the analysis must be consistent, which explains the traditional approach of waiting until the data are of sufficient quality to be subjected to the analytical methodologies currently in use. It is not true, however, that incomplete or inaccurate data are inherently useless: even the earliest and sketchiest of data can be subjected to useful analysis, the results of which can affect the direction of design. This is especially true when the absolute magnitudes of cost estimates are not of concern, but rather the relative costs of two or more design alternatives.

The distinction between relative and absolute costs is an important one for understanding both the fundamental nature of trade-off analysis and the role of information in analysis. Imagine a fixed performance cost trade-off analysis between three competing design alternatives: A, B, and C. Analysis indicates that the cost of the three alternatives respectively are 52, 24 and 22 units (units we assume are dollars multiplied by some factor). The absolute magnitudes of these costs are of no significance to the designer (and of little significance to anyone else except as rough estimates of the actual cost of the system). What is important to the designer is that alternative A is more than twice as expensive as either of the other two alternatives, and thus is probably not a good potential design path. Alternatives B and C are sufficiently close to each other in cost that it is worth

continuing to "play" with both alternative paths to see if some variation, say B' or C', might yield a significantly lower relative cost. If preliminary cost estimates are "too close to call," then the choice between design paths can be based on non-cost criteria (for example, the aesthetic beauty of a design or previous familiarity with a design scheme) or work can be continued along both design paths and the final decision deferred until more detailed cost analysis can be based on further information about both design paths.

The significance of understanding trade-off analysis in this light is two-fold. First, rough, even inaccurate information is still useful. Large cost differences will show up no matter how rough the information, while small differences in the relative costs of two alternatives merely indicate that both alternatives are worthy of further study as potential candidates for the final design path.

The second implication of this understanding of trade-off analysis is the necessity of analytic tools that can utilize the increasingly detailed information generated as the design matures. The tools must also produce estimates consistent with previous estimates and that increase in accuracy (e.g., approach the "real" cost of the system) over time. To understand this point better, let us examine the design/trade-off process more closely. In our example, three design alternatives were considered originally. Preliminary cost analyses indicated that A was an unacceptable design option, and the relative costs of alternatives B and C were close enough to warrant further design effort. [Harkening back to the previous section, we note that if the time and/or cost required to conduct this cost analysis were too

great, it is possible that path A would have been arbitrarily chosen and "locked in."]

Further "playing" with the design resulted in alternative designs B' and C'; assume that C' is chosen as the design path. As the design of C' matures, various sub-alternatives become available. The designer now must choose among these alternatives. The choice between these alternatives is based on different, more detailed issues. A cost analytic tool designed to facilitate early system trade-offs would not (indeed, for the required simplicity of use, should not) be able to differentiate between the new alternatives. What is needed is a second cost analytic tool capable of facilitating trade-off analysis at this level by utilizing the more detailed data now available. Naturally, the analytic methods of the second tool must be consistent with those of the first.

This process of continued growth of information and parallel growth of model structure must continue throughout the design process. It is important to understand that model complexity is always predicated on information availability, never the other way round (i.e., designers should never be forced to suspend the design process in order to generate input data for cost analyses, as is often done in large design projects).

Designer Interface

We have characterized the cost trade-off process as one in which various design alternatives are considered and then either pursued or rejected based on relative cost. As the design matures, the design process becomes more complicated, and more actors become involved in it.

While the initial choice between alternatives A, B and C conceivably could have been made by a single senior system designer, as the design proceeds the number of designers increases rapidly, and the problems of their communication on a uniform basis compound.

As was stated in Section 2.1, most design decisions are made by detail designers, who never see "the big picture." This myopia can be a major problem for many types of design trade-offs. Suppose, for example, that a circuit designer was trying to decide whether to use standard electronic modules (SEM's), or some other technology. The ultimate cost of his choice is strongly dependent on how other circuit board designers are constructing their boards. If, for example, many other designers were intending to use SEM's, it would reduce the system cost if this designer did as well (because of reduced spare stockage costs, among others). On another level, if the system or subsystem designer became aware that most of his detail designers were using the same SEM's, he could point out this design alternative to the remaining designers, with great potential for savings in ultimate total system cost. The problem is, how can designers be made aware of the potential cost impact of their colleagues' design efforts?

A different type of interface problem occurs when designers must deal with support specialists. For example, level of repair (LOR) analysis has traditionally been conducted by a small number of specialists late in the design process (in fact, LOR analysis is at times not conducted until the Production/Deployment phase of the WSAP). However, because of the great impact of LOR decisions on maintenance manpower and training requirements, it is critical that LOR

analysis be incorporated into the design process itself. But designers are not logistics support specialists, nor is it reasonable to expect them to become so. We have already discussed the information cost problems of having specialists at the beck and call of every designer, yet it is essential that the specialists' expertise be incorporated in the design.

The designer interface problem, then, has two aspects. First, designers must make decisions based on what other designers are doing. This information must be passed back and forth between all detail designers, subsystem and senior system planners. Second, designers are required to incorporate into their design specialized considerations not necessarily within their technical scope.

Manpower Costing

The problem of computing manpower cost correctly is far from simple. This section will briefly point out some of the difficulties arising in manpower costing, particularly in the context of the design process. What are seen as the resolutions to most of these difficulties are presented in Chapter 3, below.

Direct manpower, as distinguished from secondary or support manpower, can be broken down into two main groups: operators and maintainers. For both groups there exist some basic questions that must be answered for cost estimation: How many men are needed? Are they already available, or must new personnel be added to the platform? What is the cost of doing so in each case? How many men must be trained? What level of training must each man receive? These and other crucial costing questions are both difficult and important to answer. To answer

them, starting from scratch, requires knowledge of economics, cost accounting, personnel planning and procedures, training and other issues with which detail designers are usually unfamiliar. Yet, the designer must take these issues into account to conduct cost trade-offs correctly.

To complicate matters, cost computations for operators and maintainers must follow quite different methods. The total operator requirement, for example, is based on peak operating demand rates, whereas the maintenance manpower requirement is based on an average demand determined by the failure rates of the elements of the system, the mean time to remove and replace failed assemblies, the mean time to repair systems, the level of repair policies of the sub-elements of the system, and other factors, all of which interrelate in a complex and sometimes counter-intuitive manner. Once the maintenance manpower requirement has been determined, it is relatively straightforward (by relatively, we mean theoretically complex but computationally simple) to determine shipboard manning assignments, whereas operator manning requirements are a complicated function of equipment duty cycle, operational profile, and operator manning policies.

Even after manpower requirements are determined, computing the cost of fulfilling the requirements can be a difficult task. New questions arise: What is the cost (if any) of utilizing an already present operator, or of adding to an operator's workload? From which manpower pools should personnel be drawn? What is the least cost mix between wages and training? What is the correct cost penalty (if any) for new personnel added to a platform? These and other manpower costing

issues must be resolved for the designer by the cost trade-off method itself.

Summary

A cost trade-off system for design must fulfill the following criteria: It must offer rapid turn-around time for analysis at low cost; it must be capable of dealing with the sketchy information available during the earliest stages of design, and be able to expand to exploit the increasingly detailed information available as design matures; it must offer a method of cost communication between designers working on separate parts of the system as well as between designers and support specialists; above all, it must be simple and easy to use. It should go without saying that the system should also be conceptually correct and complete in its formulations for costing both hardware and manpower elements.

In the next section, we introduce a cost trade-off system, called a linked and graded model system, with the potential to resolve the issues raised up to this point.

2.3 LINKED AND GRADED MODEL SYSTEM

The system consists of a series of interconnected cost models. At the beginning of the design process, simple, quick-turnaround cost models are used. These are followed by increasingly complex model systems, in which values used in previous models are replaced by equations whose input data requirements are more fine-grained. A model system with this characteristic is called a graded system. The model systems are connected by a consistent mathematical structure. This feature is referred to as the linking of the models. For system aggregation models, the term "linked" is also used to indicate that model outputs from lower aggregation levels are used as input to the next higher level model.

The linked and graded model system consists of three separate model systems: a system "slide-rule" model; a slide-rule aggregation model; and a full-scale system aggregation model. Briefly, the system slide-rule model is a simple cost model, implemented on a desktop programmable calculator, used by the senior system engineer during the earliest stages of design to conduct system level cost trade-offs. The slide-rule aggregation model, used almost immediately after the system slide-rule model, is a linked slide-rule model system used by designers at three levels of aggregation: component, subsystem and system. The full-scale system aggregation model is a large production-computer cost model, similar in structure to the slide-rule aggregation model, with more complex mathematical formulations and

capable of more sophisticated cost analyses. It is used in parallel with the slide-rule aggregation model during the middle stages of design.

The next sections consist of detailed explanations of the slide-rule cost model concept, the structures of the model systems, and how the combination of the two resolves most cost trade-off issues discussed earlier.

The Slide-Rule Cost Model Concept*

Since their introduction a few years ago, an ever widening variety of uses have been found for printing programmable calculators. These low-cost tools have now reached the point that they have all the capabilities of full scale computers, but in miniature: they have limited storage and machine language. Nonetheless, mathematical cost models as complete as most production-computer driven LCC models can be programmed on these calculators.

A slide-rule cost model is a simple cost model, implemented on a programmable calculator, that helps the designer conduct cost trade-offs. The form of such a model is the following. Output costs are printed by categories (for example, spares, repair, training and so on) and total life cycle cost is calculated. Costs are estimated for several different support postures: discard upon failure, local, intermediate, or depot repair, or a mixed posture.** Running time for a slide-rule model would be a matter of seconds. Design changes are

*The material of this section is adapted from Butler, op. cit., Chapter III.

**A mixed posture occurs when the BCM rate can take on a value between 0 and 1.

entered by altering any of the few input data elements, including the major technical and cost characteristics of the equipment element. Based on rough order-of-magnitude estimates of technical parameter changes, the designer uses the model to determine immediately which design paths are the most profitable.

The time property of the slide-rule model solves the feedback delay problem discussed in Section 2.2. There is no delay at all. Thus, the process shown in Figure 2.5 is replaced by that in Figure 2.6. Several consequences of this fact are important. First,

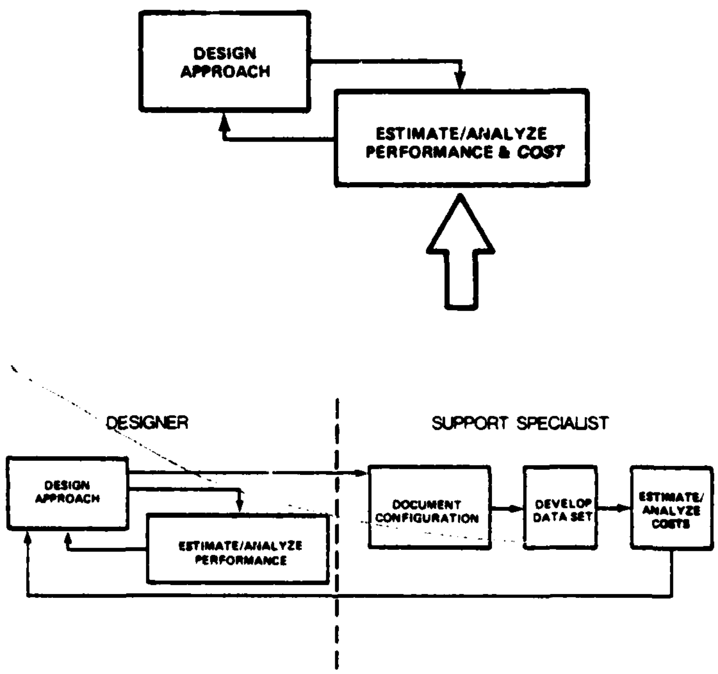

Figure 2.6 Slide-Rule LCC Model

the designer needn't prepare any detailed data form or other device requesting a trade-off from someone else. Not only does this remove the inconvenience of having to do so, but it also removes his natural shyness at the prospect of having a poor idea. No one will look at his result if he doesn't choose to show it to them. While this may seem to be a small matter, it could be significant if the social dynamics of this kind of exchange are currently inhibiting designers in doing creative work.

Second, the designer will find it so easy to test the cost implications of different design options that he will do so quickly and prevent himself from taking wrong paths at the outset. Moreover, he will tend to test a wider variety of options.

Third, one of the most important effects of collapsing the time delay in the feedback loop is that the designer will begin to learn, on a subconscious level, about the likely outcome of tradeoffs. At the high rate of use expected for these machines, he cannot but develop a "feel" for how certain kinds of tradeoffs will turn out. In the same way, he will begin to understand the interplay between, for example, support postures and the costs of test equipment, training and technical data, and similar "specialized" issues. As this knowledge is refined, the design ideas he offers will become similarly refined. Finally, the slide-rule concept sharply reduces the cost of obtaining cost trade-off information.

Both human interaction and waiting time are elements of information cost: barriers between posing a question and obtaining its answer. Both are eliminated. In addition, the machine itself remains

on the designer's desk, eliminating inconvenience costs. This is feasible since the hardware cost is so small that there is no compelling reason why every member of a design team should not have one.

The slide-rule idea provides the necessary link between cost equation systems and implementation of cost analysis at a crucial stage of the Weapon System Acquisition Process. The central idea is to supply a non-specialist with a sophisticated collection of cost analytic rules that do not require his understanding. That is, the sophistication of the mathematical structure and the economic and cost analytic elements it contains can be made opaque to the user.

2.4 USING THE LINKED AND GRADED MODEL SYSTEM IN THE WSAP

The Weapon System Acquisition Process (WSAP) for major systems is divided into four phases: Conceptual, Validation, Full-Scale Development, and Production/Deployment. The first three phases are referred to in this volume as the design phases. In this section we will make the connection between the concepts of the linked and graded model system (LGMS) and the current WSAP. Detailed descriptions of the design phases of the WSAP and the model systems used during these phases are provided in Chapters 4 through 6. Any division of a continuous process like design into separate time-phased segments is almost always arbitrary. Thus, even though we will state that a particular process occurs during a particular phase of the WSAP and a particular model is applied, such concepts are really quite flexible.

Two processes take place during the Conceptual Phase: system conceptualization and early system design. Conceptualization consists of understanding an operational requirement and determining the system capabilities necessary to meet that requirement, while in early system design alternative approaches for meeting conceptual performance and cost goals are explored. The main tool to aid planners in initial conceptualization has been parametric cost estimating models. These models can be useful in providing rough system cost estimates based on approximate technical parameters.* However, once the actual process of design begins, parametric models should be put aside and the linked and

*The reader is referred to Chapter 4 of Volume II for a discussion of the strengths and weaknesses of parametric methods.

graded model system introduced.

The System Slide-Rule Model, the first model of the linked and graded model system, is used during the early system design stage of the Conceptual Phase of the WSAP. The model uses input variables that characterize the system as a whole and the operating environment in which it is to be deployed. The System Slide-Rule Model should be as quick and simple to operate as possible. The entire input data set should consist of no more than twenty to thirty variables, of which only three or four need be altered to conduct most trade-off analyses. Life cycle costs are computed in a few seconds. To do this requires a rather simple set of cost equations that make some healthy asumptions about the nature of the subelements of the system. Doing so, however, allows the senior system designer to compare, quickly and easily, the cost impact of broad alternative system approaches. He will be able to eliminate immediately the least cost-effective design paths and to concentrate on the most desirable.

In the Validation Phase RFP's are issued, contractors selected, and the system prototype studied, designed, built and tested. Thus, most of the actual concrete design of the system takes place during the Validation Phase.

The Slide-Rule Aggregation Model System, the second model system of the LGMS, is introduced at the beginning of the Validation Phase. It consists of three linked slide-rule models at three aggregation levels: component, subsystem and system.* The output of each model

*The choice of three aggregation levels and the design hierarchy

is used as input to the next higher aggregation le"el model. The Slide-Rule Aggregation Model System is used as follows. The system designer makes an initial breakdown of the system into "dummy" or straw-man subsystems, each of which is characterized by the performance and cost goals envisioned by the system designer. He conducts system design trade-offs by creating new subsystems and inputting them to the system aggregation slide-rule model: the highest level model of the Slide-Rule Aggregation Model System. Thus, unlike the System Slide-Rule Model, which makes gross assumptions about the system subelements, the system aggregation slide-rule model builds up the system as the sum of all its subsystems.

The data sets describing dummy subsystems are given to subsystem designers, each of whom has a subsystem aggregation slide-rule model, indentical in structure to the system aggregation slide-rule model, but keyed to the design of subsystems.* The output of the subsystem model is in exactly the same form as the original dummy subsystem. Thus as the design of the subsystem matures, the designer replaces the dummy values with real data characterizing the status of his design. Gradually, all the dummy subsystems input to the system aggregation model are replaced by real subsystem descriptions which the system designer uses to conduct further system level trade-offs.

(cont.) of component, subsystem and system is arbitrary - in fact, any aggregation structure can be used. This point will be dealt with in more detail in Chapter 5.

*It may help in conceptualizing this system to think of data sets as physical entities. If desk top programmable calculators are used, each subsystem and component data set would be in the form of a magnetic card.

At the base of the design hierarchy is the Component Slide-Rule Model. The output of this model is used as input by the Subsystem Model (that is, the subsystem is originally built up of dummy components, which are gradually replaced by real component designs). The Component Model is similar in structure to the original System Slide Rule Model - it considers the component as a whole by making assumptions about the uniform nature of the subelements of the component rather than explicitly building up the component from separate, building-block elements.

The Slide-Rule Aggregation Model System successfully meets the cost trade-off system criteria suggested in Section 2.2: rapid information turn-around time at low cost (use of programmable calculators, for example); the utilization of increasingly detailed information as the design matures (initial dummy estimates are replaced over time by real data on system elements, themselves refined as the effort continues); and designer interface (the magnetic cards passed from designer to designer contain variables characterizing the design status of the system and the operating environment into which it is to be placed and these variables impact the design process by altering the cost estimates produced by the models).*

Part way through the Validation Phase, the general structure of the design is usually settled. When this happens, its structural rigidity

*Note also that the use of magnetic card data sets provides a management control and reporting device useful to engineering managers, to the extent that the models are driven by technical, rather than cost parameters. In addition, system level design alterations can be communicated to detail designers through the alteration of data sets returned to them.

can be exploited by the introduction of a more detailed and demanding cost model apparatus. While the design staff continues to use the simpler slide-rule type models, a production computer model can be readied and tailored to the design's structure. The data sets are gradually shifted to the larger model, and augmented with new information. The new model is the full-scale aggregation model. The primary advantage of the new model is that it allows for the simultaneous consideration of all the elements of the system, making it possible to deal with such issues as commonality, phased training and production schedules, and generally more detailed data sets (these issues will be discussed in Chapter 6).

The final phase of the WSAP is the Production/Deployment Phase, during which the system is manufactured, personnel trained, logistics support organized and the system tested and made operational.

The acquisition process is portrayed in Figure 2.7. Based on the amount and type of information available (see the foot of the figure), different cost methods are recommended at different stages of the acquisition process. Note that the formally defined phases of the weapon system acquisition process (top row of the figure) do not line up well with the periods during which each cost analysis method is used. This is a natural outgrowth of the fact that each decision point gives rise to changes in the level of information. At the start of the phase the new information is still unavailable so cost methods used earlier are still appropriate. By the end of each phase, however, its purpose - expansion of information about the new system - has been fulfilled and the new tools of cost analysis are required to fully exploit that progress.

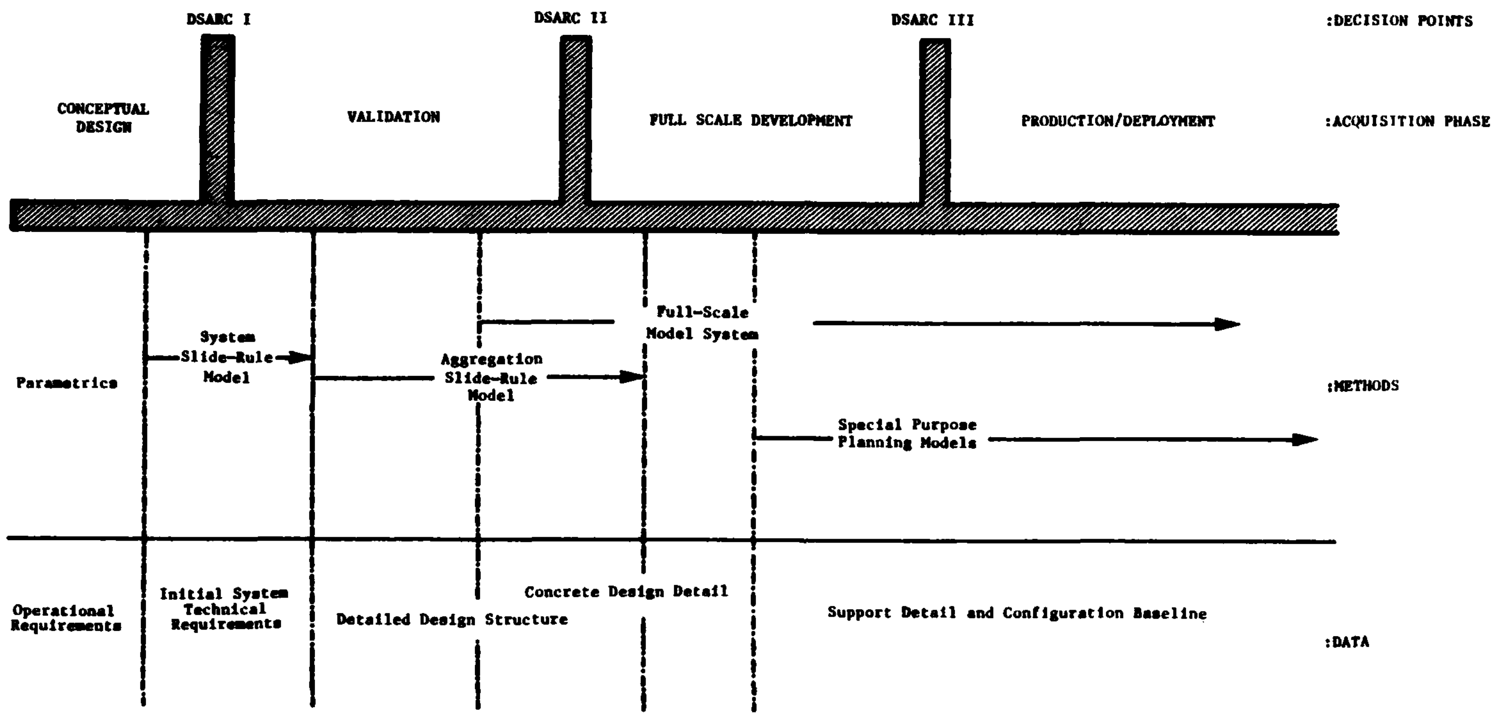

Figure 2.7 Cost Methods and the Acquisition Process

3.0 MODELLING MANPOWER COST

In the last section four constraints on a hardware/manpower trade-off design system were discussed: information feedback time and cost, information utilization, designer interface, and manpower costing. The linked and graded model system was presented as the solution to the first three requirements; this section deals with the problems and solutions of correct manpower costing.

In modelling manpower cost, it is essential to make the fundamental assumption that manpower costs are in fact determined by equipment design. If one accepts the statement that the cost allocated to Naval personnel procurement bares no relationship to the decision to procure any hardware element (that is, the manpower budget has already been determined without regard to the equipment in question), then there is no manpower cost associated with the equipment and the entire concept of hardware/manpower trade-off analysis breaks down completely.*

Yet, the fact is that personnel are already in the Navy, and most new equipments merely utilize these existing personnel. There are real costs in utilizing these personnel only if one assumes (quite reasonably) that utilizing personnel ultimately results in the Navy either procuring additional personnel, increasing its total manpower budget, or retaining personnel who otherwise would have been let go, a

*See Volume II, Chapter 2.

foregone reduction in the Naval manpower budget.

The manpower cost modelling methodologies presented in this section assume that the Navy is built up of a number of different manpower tools. Some pools are small (for example, the number of available specialists in a particular field on a particular platform), other pools are quite large. A large manpower pool of particular importance is the pool of general Naval enlisted personnel available for assignment to a specialized billet. The basic approach of the manpower cost equations is to determine the costs involved in removing a man from one manpower pool and placing him in another. While this approach to manpower costing at first appears to be quite different from current Navy manpower costing methodologies, it is actually a generalization of current techniques. We will demonstrate how current techniques can be naturally derived as a special case of the manpower costing equations developed in this chapter.

Before any costs can be discussed, it is necessary to introduce some basic cost concepts. From the point of view of a new equipment, costs can be divided into two parts: costs arising as a direct result of the deployment of the system, and costs that would have occurred whether or not the system had been deployed. The first are costs directly allocable to the equipment, and are called the marginal cost of the equipment. The second are overhead costs. The manpower costing equations charge to the equipment only the marginal costs of the eanquipment. It will turn out that the marginal personnel cost of equipment include some unexpected items which are rarely, if ever, found in current manpower costing methodologies.

What, then, are the costs of utilizing Naval manpower? Basically, they can be divided into three categories: wage, training, and other costs. "Wage" or compensation cost is the sum of costs associated with a duty billet. It includes direct salary, initial training, allowances, benefits, transportation and a balancing item for non-productive time. As used in this report, wage costs are directly comparable to those computed in the Billet Cost Model (BCM) with the exception that they exclude advanced training.

One way to look at wage cost is as an "opportunity" cost.* Since the personnel who will man new equipment were already in the Navy when the equipment was deployed, they are already paid for. The cost of an equipment utilizing a man's time is that by doing so the time is no longer available for other work. Thus the real cost of using a man on a new equipment is the foregone opportunity of using him on something else. To be precise, the relevant foregone opportunity is the highest valued among all possibilities.

Wage costs are closely linked to training costs. Suppose, for example, that a man receives specialized training for an equipment and as a result his cost to the Navy rises (for three reasons: first, while he is training, he is unavailable for other work, which must be provided for or foregone by the Navy; second, his seniority and thus his base pay increases during the training period and third, he may receive promotion or additional benefits because of his training either immediately or during his subsequent career). This rise in cost is allocable to the

*This and other economic concepts are discussed fully in Volume II, Chapters 2 and 3 of this report.

equipment's acquisition. The reason for this is clear: if it weren't for the equipment, the man wouldn't have received the training and the increment in his wage would not have occurred.

The link between wage and training can also be understood through the concepts of underemployment and overpayment. Suppose again that a man's cost is raised due to training for an equipment, but he does not spend all of his time on that equipment. Assume that during his "non-prime" time (that is, time spent working on something other than what he was trained for) he is assigned to general labor duties. For the time that he is not working on the equipment, he is being overpayed by the difference between his cost and the normal cost for general labor.* The Navy could have procured the same services at less cost for the man's non-prime time, during which he provided less value (output) than cost (input). This overpayment is a marginal cost of the equipment. A man in this position is underutilized, or underemployed.**

The concept of value is an important one for wage costs. While conceptually it is not difficult to measure the wage, or input cost of a man (practically, however, the problem is an extremely difficult one from a computational and cost accounting point of view) there is no good way to measure the value to the Navy of a man's output. Therefore, a

*The rubric "general labor" is used throughout this report to denote a worker with lower skill level than someone specialized in a particular area.

**Interestingly, the Navy recognized underutilization up to 1899 by adjusting pay scales downward for sailors who were on leave or awaiting assignment. See Cylke, S., "A Brief History of Naval Compensation," RD-112, The Assessment Group, Santa Monica, 1978.

basic assumption used throughout the derivation of the manpower cost equations is that the value of a billet to the Navy is accurately reflected by the cost of filling that billet. In other words, if a general labor billet cost the Navy $10,000 a year, then that billet produces work which is worth $10,000 (to the Navy). It is further assumed that non-prime time is not wasted; rather the time is devoted to general duty assignments, for which the Navy receives output equivalent to that of a general labor billet. To some extent, these assumptions cater to a "make work" philosophy. Certainly there are cases in which personnel are put to work simply because they are available for work. Their output, "paint chipping," is actually of little value.*

Training costs are incurred whenever a new equipment is deployed. It is necessary to differentiate between three different types of training. The first type is the basic training course which every enlisted man in the Navy receives. This cost is accounted for in personnel billet costs. The next training course is the basic course in the fundamentals of fields of specialization. This course, the "A" school, can be quite lengthy. Whether this course is a marginal cost of the new equipment depends on whether the equipment's deployment required new personnel. The final training course is the specialized course for the new equipment, the "C" school. This course is taken by all personnel assigned to the equipment. It's cost is directly allocable to the equipment.

*Appendix A is a detailed discussion and rationale for the dollar difference between the billet cost of a skilled man and that of a general laborer.

The final manpower cost element is "other" costs. These include such costs as security clearances, the administrative and hotel costs of assigning new men (if any) to platforms, the additional support personnel costs which may be incurred by the addition of he equipment and its personnel, and similar costs.

There are two types of other costs, one for personnel who were already on-board the platform, the other for new additions to the platinm end strength. The main potential element in other costs in on-board personnel is the cost of any additional security clearance required to man the system. Other costs for new personnel include security clearances, and in addition, all the costs involved in adding new personnel to the platform.

We have now briefly introduced most of the theoretical issues necessary to the development of correct manpower costing formulations. These and other issues are reintroduced in the course of the development of the cost equations, and are discussed in detail in Volume II of this report. However, what has been presented provides sufficient background to quickly develop a generalized version of the basic manpower cost equation, which we propose to do now. This equation is not the final form of the manpower cost formula. It is presented here solely to provide a structure for the rest of the discussion. The cost equation is the following:

$$\text{Manpower cost} = MB + A\delta B + ATa + TTc + SZ.$$

The wage, or opportunity, cost of meeting the manpower requirement, M, for the equipment is the product of M and the wage or

billet cost of the quantity of personnel, B. The rise in billet cost, δB, attributable to receiving the basic training course is a cost incurred by all personnel who receive "A" school, A, as a direct result of the equipment deployment. In addition, these personnel incur the training course cost for "A" school, Ta. Other costs, Z, are incurred for any new personnel who must be added to the platform, S. Finally, the cost of "C" school, Tc, is incurred by all personnel, T.

Note the strong connection between wage and training costs. This connection will require that wage and training costs be developed simultaneously, although traditionally they have been treated as separate subjects. The connection between wage and training will become particularly apparent when we turn to a discussion of determining values for A, δB, and S.

As was stated, the manpower equation presented here is merely intended to provide some focus for the subsequent sections. In Section 3.1, the manpower cost equations are derived in full, using two alternative approaches. In addition, several special cases for the equation are explored, and it is shown how the reduced form of the equation is consistent with current manpower costing practices. Section 3.2 turns to the problems of arriving at values for the input variables to the cost equations. The chapter is briefly summarized in Section 3.3.

3.1 MANPOWER COST EQUATIONS

Manpower Pools

As was stated in the previous section, the guidelines look at the Navy as consisting of existing manpower pools. Personnel costs arise when men are removed from one manpower pool and placed in another. In other words, in order to determine the cost of a man, it is necessary to know not only where he is, but where he used to be.

Every new equipment deployed on a platform has with it a requirement for a trained personnel, who are drawn from various manpower pools. Three pools are relevant here. The first pool consists of all on-board personnel who have already received the basic "A" school training required for the equipment, who are partially or fully underutilized and hence available to be assigned to the new equipment. It is assumed that personnel in this pool spend their underutilized time doing general labor, so that the Navy is getting at least some return. This pool, called the AN pool, consists only of the underutilized parts of people's time and thus can take non-integer values. If, for example, there is only one underutilized trained man on the platform who spends 75% of this time on his prime activity and 25% on general labor, then the AN pool consists of .25 men. The second manpower pool consists of the personnel on board the platform who have not been to "A" school but are capable of absorbing this training and being assigned to the new equipment. At present, they are wholly devoted to general labor. Hence

the second manpower pool, called the AG pool, can only take on integer values. The third manpower pool consists of the general pool of available general duty sailors not assigned to the ship. Like the AG pool, the third manpower pool, called the AS pool, can take on only integer values.

Officially, the AS pool does not exist. According to OPNAV Instruction 5300.3A, "There is no pool of unprogrammed manpower from which to allocate billets and positions in support of unplanned requirements."* Therefore, drawing from the AS pool must be compensated by "withdrawing billets from position previously approved for other Navy programs or activities." If the Navy is not willing to forego the withdrawn billets, then ultimately the total manpower force of the Navy will have to be increased. However, OPNAVINST 5300.3A goes on to state: "As a general rule, the program sponsor cannot request a net manpower increase for the current fiscal year or the budget year when such a request would cause total end strength to exceed the limitations established by Congress and funded in the MPN/O&MN appropriations."** The manpower cost equations must reflect the high cost of drawing from the AS pool. At best, drawing from the AS pool implies that the costs of adding additional personnel to the platform must be borne; at worst the total cost of recruiting new personnel and increasing the total

*OPNAV Instruction 5300.3A, "Development and review of manpower requirements for new ships, programs, systems, and hardware," dtd 25 September 1975, pg. 2.

**Ibid., pg. 3.

manpower end strength of the Navy must be allocated to the equipment.

The size of the AN and AG pools are an important factor in the design of an equipment which is to be deployed on a platform. Clearly, it is most desirable to draw manpower only from the AN pool, since in this case the manpower requirement is met without the necessity of providing expensive "A" school training courses or adding new personnel to the ship's complement. An additional investment in hardware development which allows the manpower requirement to be met strictly from within the AN pool may more than pay for itself in reduced training costs. Considerable hardware investment is worthwhile to avoid the large costs involved in drawing from the AS pool. (There are cases, however, in which it is a lower cost option to draw personnel from the AG or even AS pools rather than the AN pool. These cases will be discussed later when the least cost algorithims for drawing from the manpower pools are developed.)

From the point of view of the designer, the AS pool may be considered inexhaustable. In fact, he need give little or no consideration to the size and composition of this manpower pool. This is not the case for the AN and AG pools, however - they _must_ be included in the design process: the proper conduct of hardware/manpower trade-offs leaves no alternative but to force the design engineer to consider the manpower availability characteristics of the operating environment into which his system is to be deployed. There are no conceptual or even practical measurement problems involved in obtaining real values for AN and AG for a wide variety of ship classes and NEC specialties. Any personnel supervisor can tell a data

collector how many men work under him and what percentage of their time is spent on primary activities and what percentage on other duties. In addition, once the values for AN and AG are provided for the designer, he need no longer concern himself with them if he doesn't want to; the manpower equations incorporated into his cost models will automatically compute the least cost method for drawing from the pools and the resultant manpower cost.

Derivations of the Manpower Cost Equation

In this section we derive the manpower cost equation using two different approaches. The first approach looks at the costs incurred by drawing from each of the three manpower pools, AN, AG and AS. The second approach derives manpower cost as the sum of direct wage cost for the time spent on prime equipment plus the overpayment costs of adding to the AN pool.

To get started, we need to define some terms. As before, let M be the total manpower requirement for the equipment. M is a real number, whose units are men, or equivalently, billets. Define An, Ag and As, respectively, as the number of billets utilized by the equipment from the AN, AG and AS manpower pools. The number of men actually drawn from each pool are I(An), I(Ag) and I(As), where I(x) is an operator which rounds the value of x to the next higher integer, that is, I(2.3)=3 and I(2)=2. By definition, An + Ag + As = M. As an example, suppose M=2.5, AN=1.3, and AG=5 (recall that AS may be considered to be inexhaustably large). The manpower requirement is met by drawing one man from the AN pool, who works full-time on the equipment, and two from the AG pool, one of whom works full-time on the

equipment, and the other half-time. Thus, An=1, Ag=1.5, and As=0.* Also, I(An)=1 and I(Ag)=2. In addition, we define Bn as the billet cost for trained personnel, and Bg as as the billet cost for a general laborer. Ta and Tc are defined as before as the cost of "A" and "C" schools.

Finally, recall that it was necessary to differentiate between two types of "other" costs; one for on-board personnel, the other for new additions to the platform. Let Z and Zs, respectively, represent these costs. The main potential element for Z is the cost of any additional security clearances required for existing personnel to man the new system. Zs includes security clearance costs, and in addition all other costs involved in adding new personnel to the platform. With these definitions in hand, it is now possible to proceed to the derivation of the cost equation.

In the first derivation, we examine the costs of removing men from each of the three manpower pools and placing them in a new manpower pool, namely the pool of personnel assigned to the equipment.

We first determine the cost of utilizing personnel from the AN pool. An men are utilized from the AN pool and set to work on the new equipment. What is the cost of doing so? Recall that there are three major cost elements: wage, training and other costs. Note first of all that I(An) men receive training. By definition of the AN pool, only "C" training is required. These I(An) personnel also incur any on-board

*The reader may wonder why the extra .3 billet available in the AN pool was not utilized. The reason for this will become clear when the least-cost algorithms for drawing from the manpower pools are developed in Section 3.2.

"other" costs. The training and other costs for the AN pool are expressed by I(An)[Tc + Z]. To determine wage costs, one computes the cost to the Navy of replacing the labor lost from the AN pool by removing An men from it. This cost is AnBg. Note that the billet cost used is Bg, even though members of the AN pool receive a higher base pay due to their advanced training. The total cost, then, of utilizing An men from the AN pool is AnBg + I(An)[Tc + Z].

The costs of utilizing men from the AG pool are similar in their derivation to those of the AN pool. Training and other costs are expressed by I(Ag)[Ta + Tc +Z], since personnel from the AG pool must receive "A" as well as "C" school training. The wage cost of the AG pool, however, must include not only the cost of replacing the labor lost to the AG pool (AgBg), but also the rise in cost of the personnel resulting from the "A" school which they receive. Everyone trained from the AG pool, I(Ag), carries this cost increase, represented by Bn-Bg. The total cost for the AG pool is therefore AgBg + I(An)[(Bn-Bg) + (Ta+Tc) + Z].

The costs of drawing men from the AS pool are the same as for the AG pool, the only (but extremely important) difference being that the value for Z is replaced by the larger value of Zs. The cost is: AsBg + I(As)[(Bn-Bg) + (Ta+Tc) + Zs].

Combining the costs of utilizing men from the three manpower pools and substituting M for (An + Ag + As), we obtain the following manpower cost equation:

$$\text{Cost} = MBg + [I(Ag)+I(As)](Bn-Bg) + [I(An)+I(Ag)+I(As)]Tc + [I(Ag)+I(As)]Ta + [I(An)+I(Ag)]Z + I(As)Zs$$

When the least-cost algorithms for drawing personnel from the manpower pools are developed in a later section, it will be shown that it is possible to choose An, Ag and As such that I(An)+I(Ag)+I(As) = I(M). If we set A, the number of personnel who receive "A" school training, at A = I(Ag)+I(As), and B, the number of utilized on-board personnel, at B = I(An)+I(Ag), then we can present the following expression for the cost equation:

$$\text{Cost} = MBg + A(Bn-Bg) + I(M)Tc + ATa + BZ + I(As)Zs.$$

This formulation contains several elements that give rise to questions. For example, why is the billet cost, Bg, used to estimate the cost of trained labor? Why is the number of people to be trained used as part of wage cost rather than simply training cost? Most questions can be answered by deriving the equation again, but from a different direction. The second approach looks at manpower cost from the point of view of a new system, and asks what costs must be directly allocated to that system. In particular, let us look at wage costs.

There are two wage costs: the direct wages for work on the system, plus the overpayments for other work which results due to the system's deployment. Recall that overpayment costs arise because trained personnel are not fully utilized at their specialty. Adding to the AN pool (consisting of trained personnel doing general labor) has the effect of increasing overpayments. That is, if a man is trained and only 75% utilized at his specialty, then he will be overpayed during the 25% of time he spends on general duties. By definition, .25 man is added to the AN pool. The direct allocation approach to wage costing

therefore states that the wage cost for a system is the sum of the direct wage costs, MBn, plus the overpayment costs (or refunds) of all additions (or removals) from the AN pool. This cost is equal to the difference in the pool size, multiplied by the difference between the trained and general billet rates, Bn-Bg. Note that this cost can be negative - a credit - if the deployment of the new system results in a net reduction of the size of the AN pool.

The additions and removals to the AN pool are the following. I(Ag) personnel from the AG pool are trained, but only Ag are utilized; a net increase to the AN pool of I(Ag)-Ag. Similarly, the AN pool is increased by I(As)-As. Finally, the AN pool is reduced by An. This approach to the wage elements of the manpower cost equations yields a different result:

$$\text{Wage cost} = MBn + [(I(Ag)-Ag) + (I(As)-As) - An](Bn-Bg).$$

By using the relation M = An+Ag+As, this can be rearranged to form:

$$MBn - M(Bn-Bg) + [I(Ag)+I(As)](Bn-Bg),$$

which becomes the same expression developed above (remembering that I(Ag)+I(As) = A):

$$\text{Wage Cost} = MBg + A(Bn-Bg).$$

Special Cases of the Manpower Cost Equations

The manpower costing equation is a generalized formulation which correctly computes manpower costs for a wide variety of cases. One special case of particular interest occurs when the manpower

requirement, M, is entirely met from the AN pool (that is, $M<AN$). In this case, $M=An$, $Ag=As=0$. If in addition there are no security clearance costs, the manpower cost equation reduces to:

$$\text{Cost} = MBg + I(M)Tc.$$

This formulation is interesting because of its inherent simplicity, because of the large costs which are avoided, because of its similarity to traditional manpower costing techniques, and because it is one of the most common cases (especially for maintenance manpower). Note that large jumps in manpower cost occur only when M crosses the threshold causing I(M) to jump to a higher or lower integer value. The implications of this work in two directions. First, a small increase in hardware cost can, at times, push M below an integer threshold, allowing a significant manpower reduction. On the other hand, once an integer threshold has been breached, M can be further increased (to the next integer threshold) with only modest increases in total manpower cost. Hardware/ manpower trade-offs do <u>not</u> always result in minimum manpower. This is especially the case once M is less than one (common for the maintenance manpower requirement of modern electronic systems). It is extremely difficult and expensive to reduce a maintenance manpower requirement from a value which is already low to one yet lower; the cost savings on maintenance personnel are not likely to compensate for the increased hardware costs. By trading off a little reliability (without crossing an integer threshold for maintenance manpower), significant hardware savings can at times be achieved with only moderate increases

in manpower cost.

Increasing M to the point that the AN pool is no longer sufficient to fulfill the manpower requirement, however, will immediately increase manpower costs by at least Bn-Bg+Ta (if the additional manpower can be drawn from the AG pool) or by Bn-Bg+Ta+Zs (if new personnel must be added to the platform). The preceeding discussion further emphasizes that accurate estimates of the size of the AN and AG pools, and an appreciation of their roles in determining manpower costs, is essential for developing useful hardware/manpower trade-off cost methods.

A final special case of importance occurs when Bn=Bg. An implication of this equality is that the distinction between the AN and AG manpower pools is eliminated. This can be exploited to create simplified versions of the manpower cost equation suitable for inclusion in slide-rule models used during the early design phases. An example of such a simplified cost equation is the following:

$$\text{Cost} = MB + I(M)Tc + N(Ta + Zs).$$

This formulation pays a wage cost B, provides specialized training for all personnel, and requires all new additions to the platform, N, to receive "A" school training and pay the additional costs of being added to the ship's complement. (Such a simplified equation would only be used if machine limitations do not allow a more complete version).

3.2 LINKING EQUIPMENT DESIGN TO MANPOWER COST

By itself, the manpower cost equation developed in Section 3.1 is of little value to the designer. It tells the designer what the manpower costs are only after he has determined the values for several input variables. The equation gives no indication of how the values for these input variables are to be determined. This section fills the gap by providing guidelines for determining values for the manpower requirements, training, billet, and other costs as a function of equipment design. In some cases the guidelines will consist of general discussions of the issues involved in determining the input values; in others, rigorous mathematical structures will be developed. In all cases, it must again be emphasized that the methods presented here are only guidelines; other methodologies pertinent to a given case can and should be used where available. The methods presented here are keyed for use in the linked and graded model system, developed in Chapter 2, used during the early design phases of the WSAP. Chapters 4 through 6 will present examples of the methodologies developed in this section applied to each of the three design phases.

Training Costs (Ta and Tc)

Training costs are one of the largest components of total manpower cost; substantial training costs can be incurred even for equipments with small manpower requirements. Every man-day added to the

training course requirement of a system can add an additional quarter of a million dollars to the total system life cycle cost for a widely deployed system.* In addition, training can be wasted on underutilized personnel, unless training requirements are properly integrated with other manpower planning.

There are three basic training courses which enter into manpower costs. The first, basic training, is incorporated in the total billet cost of all personnel. The second course is "A" school, and the third and final training course is the specialized course specific to the new system, "C" school. The costs of both "A" and "C" school must be considered in conducting system design/cost trade-offs.

"A" school is an expensive training course for the Navy. The course can be quite long. Students' and instructors' salaries must be paid for the length of the course, and the former increase with the students' seniority. The materials cost of the training course can also be significant. In addition, "A" school can increase the total cost of personnel to the Navy by increasing the probability that they will enter more highly paid positions within the Navy. It is also quite likely that providing advanced training increases the probability that recipiants will leave the Navy at the end of their enlistment period to obtain higher paying work in the private sector.

The designer should think of training costs in terms of course length. The units of time should depend on the level at which the

*This calculation assumes a $200/man-day training course cost for a system deployed on 250 ships over a ten year life cycle with an annual personnel turnover rate of 40%.

designer is working: the system designer might think in terms of class-weeks; the detail designer might consider the contribution of his component to total training in terms of class-hours. In each case, the course length would be multiplied by an average training cost in the appropriate units.

The cost of attendance at "A" school for the appropriate NEC is provided for the system designer by the Navy program office. The designer may either use this course, design his own "A" school course, or eliminate "A" school altogether, expanding the "C" school course accordingly. Installing a new "A" school carries special one-time costs which may be quite high and must, in any case, be estimated outside the structure dealt with here.

The cost of "C" school can be broken up into the contributions of the subelements of the system to total system specialized training cost. Because of the different nature of training courses for operators and maintainers, the aggregation structure in these two cases are slightly different. The maintenance personnel training structure is essentially an expanded version of the operators' "C" school course aggregation structure.

Operator "C" school costs are determined as follows. First the system designer makes an initial estimate of the total course length. After the initial subsystem breakdown has been accomplished, this training course length is equally divided among all the subsystems and system specific training costs (or the cost can be proportioned in other, less arbitrary ways, if sufficient information is available early

in the design process).* As they achieve a better understanding of the subsystems, the subsystem designers replace the dummy values for training cost with their own estimates of subsystem training requirements. The estimates are passed up to the system designer, who also modifies the system specific training course cost estimate. As an example, the breakdown of the training course cost for a system containing N subsystems would be the following:

Initial system level estimate: $Tc = T \times C$,

where T is a course length estimate provided by the system designer and C is the dollar cost per unit time per student. The latter should be provided by the Navy program office.

Initial subsystem breakdown:

$$Tc = [NTc(\text{subsystem}) + Tc(\text{system})]C$$

Tc(subsystem) for all subsystems, and Tc(system-specific) are initially set equal to T/(N+1). These initial, "dummy" estimates are then modified by subsystem designers. The system "C" school training course estimate, therefore, becomes:

$$Tc = [Tc(\text{system}) + \sum_{j=1}^{N} Tc_j(\text{subsystem})]C$$

*Recall the discussion earlier of the arbitrariness of the system, subsystem, component nomenclature. While it is useful for a cost model to be able to accomodate a break-out of operator training costs by a second indenture level, it may be inappropriate in some cases. For example, a radar set has several subsystems, but operators must treat the equipment as a single entity. Model builders must take care that their indenture structure makes sense for different aspects of the overall cost problems: spares are computed at the lowest removable assembly level, for example, while operator training is isolated to similarly meaningf ' aggregates of equipment.

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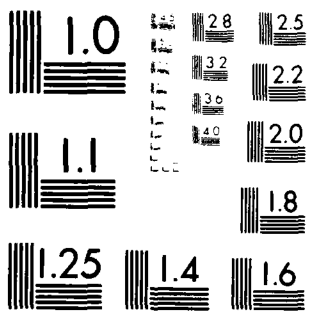

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Because operators do not generally deal with any part of a system smaller than a subsystem, the training course for operators is not broken down further than the subsystem level. This is not the case for maintenance personnel, however. Each component of the system has the potential for adding to the training course requirement for maintenance technicians. In addition, maintenance training requirements are a direct function of the level of repair policies for the elements of the system. For example, the maintenance training requirement for a system entirely composed of throw-away modules should be significantly less than that for a system composed largely of repairable assemblies.

In order to build up a structure for computing maintenance training course requirements, it is first necessary to define some terms and concepts. Maintenance action on an assembly consists of two steps. First, the failed assembly is removed from its container and a replacement assembly put in its place. The failed assembly is then either thrown away or repaired, depending on its level of repair assignment. Repair of the assembly consists of isolating, removing and replacing the failed element(s) of the next lower indenture level.*

Let us imagine a three indenture level model system in which the first level represents the SRAs, the second level the WRAs, and the highest level the system itself. As before, the system designer makes an intial estimate of the training course requirement. The

*Standard Navy nomenclature calls items removable at the system weapon replaceable assemblies (WRAs) and their elements ship replaceable assemblies (SRAs). But these terms are as arbitrary as system, subsystem and component, since election of level of repair should be made on the basis of analysis - not a naming convention.

training course cost estimate can be computed as follows:

$$Tc = T + TrR,$$

where T is an initial estimate of the training course length to learn to remove and replace all of the WRAs of the system, Tr a theoretical course length necessary to train maintenance technicians to repair every WRA, and R the estimated percentage of WRAs which will actually be coded repair. The initial training length estimate presented to each subsystem designer would be Tc/N, where N is the number of WRAs in the system; the "dummy" training course length that each SRA designer starts out with would be Tc/Nw, where w is the number of SRAs in the WRA.

Dummy values for training cost are then replaced with an estimate of real training costs aggregated over indenture levels. Working from the bottom up, the equation aggregation structure is as follows:

$$\text{SRA:} \quad Tc_i = TRR_i + Tr_i R_i,$$

where TRR_i is the training necessary to remove and replace the ith SRA, Tr_i is the training to repair it, and R_i is a binary switch set to 1 if the SRA is coded local repair, and 0 of it is coded discard or repair at another echelon.

$$\text{WRA:} \quad Tc_j = TRR_j + [\sum_{i=1}^{w_j} Tc_i]R_j,$$

where TRR and R are defined as before, only this time applying to the jth WRA.

$$\text{System:} \quad Tc = TS + \sum_{j=1}^{N} Tc_j$$

where TS is the system level maintenance training other than the removal and replacement of WRAs (e.g. system orientation).

In this manner, the maintenance training course is built up from the individual contributions of each element of the system, which in turn depend on the level of repair assignments for the element and its subelements. Note that if a WRA is coded discard (R_j=0), the WRA designer should instruct the designers of all SRAs in his WRA to plan their elements for discard as well. There is one exception to the rule, however: the same SRA may be utilized in two different WRA's, one coded repair, the other coded discard. This is one example of a general class of commonality issues, discussed in Chapter 6, below. Note also that Tr_i, the training necessary to repair the ith SRA, can be defined as the sum of all TRR_k's in the SRA, where TRR_k is the training necessary to remove and replace the kth sub-SRA in the SRA. The three-indenture level aggregation structure presented here, however, does not include sub-SRAs explicitly. These two points are mentioned to emphasize that the training cost equations above are only examples of the type of aggregation system and cost inputs which should be used to determine training cost. Other aggregation systems (for example, a four indenture level system) or other ways of defining repair, removal and replacement costs are possible. In addition, more detailed level of repair analysis can be incorporated into the maintenance training cost equations.

Manpower Requirements (M, An, Ag, As)

Clearly one of the most critical issues which must be resolved for conducting hardware manpower trade-offs is a correct determination

of manpower requirements based on equipment design. Doing so is a four step process: first, total hourly manpower demand must be determined; second, this demand must be converted into real personnel billets; third, the billet demand must be met by drawing from appropriate manpower pools; and fourth, the cost of drawing from the pools must be computed. In the following sections we will develop steps one and two, first for maintenance personnel, then for operators, for there are significant differences in the methodologies used for these two groups. Then the least-cost algorithms for drawing from the manpower pools will be developed. Note that the fourth step, determining manpower costs based on the demands from each manpower pool, has already been covered in Section 3.1.

Determining the Demand for Maintenance Manpower

The maintenance manpower requirement for an assembly is a complex function of the system duty cycle, operating hours, mean time between failure, mean time to repair, level of repair assignment, and other elements. Many formulations, some simpler, some more complex, are possible. Specific formulae appropriate to different design phases are developed in Chapters 4, 5 and 6. All of the maintenance manpower formulations, however, have the same basic structure presented here.

Before we derive the maintenance manpower requirement, it is necessary to introduce the concepts of mean time to repair (MTTR), mean time to remove and replace (MTRR), and the types of maintenance action. The distinction between repair and removal and replacement was covered in the previous section. MTTR and MTRR are the average total times required to perform the entire maintenance action. This time includes

four distinct processes:*

> Make ready: includes obtaining necessary instruction manuals, tools and materials, transit to the work area, and removal of interferences. Research necessary to determine part requirements and execution of supply forms are also included in this element.
>
> Accomplishment of maintenance action: for MTRR, this includes opening of equipment, fault isolation, removal and replacement, testing and adjustment, and closing equipment. For MTTR, this includes effecting the necessary repairs.
>
> Put away: this includes replacement of interferences, necessary cleanup, return of tools, and required transits.
>
> Data recording: includes completion of necessary forms to report the action taken, and preparation of either a repair request (if the repair is beyond the capability of organizational level maintenance) or a request for a new part, depending on the level of repair assignment.

Most definitions of MTTR include only the second (and sometimes the first) element of maintenance repair time. MTTR and MTRR as used here, however, imply the entire time required for all elements.**

There are three types of maintenance action: corrective, preventative, and facility maintenance. Corrective maintenance is work accomplished on an unscheduled basis because of malfunction, failure, or deterioration; preventative maintenance is work accomplished in response

*The following definitions are taken from OPNAV 10P-23, "Guide to the Preparation of Ship Manning Documents, Volume I-Policy Statement," p. III-9. The Guide to the Preparation of Ship Manning Documents (from now on referred to as 10-P) will be used as the source of many examples throughout the remainder of this chapter. It is recognized, however, that 10-P is considered somewhat out-of-date. Thus, any actual data presented from 10-P should be considered to be for illustrative purposes only - not recommendations for values of parameters used in Navy cost models.

**According to 10-P (pg. III-11), the current practice is to apply a 30% factor (to MTTR) for make ready, put away and data recording, and a 20% productive allowance factor. The productive allowance factor will be discussed below.

to scheduled requirements; facility maintenance is work accomplished to maintain cleanliness and to preserve the hull, superstructure and all equipment against corrosion or deterioration.

The first step in determining the total maintenance manpower requirement is to determine the corrective maintenance requirement, based on the hourly demand; that is, the number of system failures per hour. System failures are in fact component failures; the total system failure rate is the sum of the failure rates for all its components. The presentation of corrective maintenance manpower determination, therefore, will begin at the component level and work its way up to the entire system. In Chapter 4, a method for approximating component failure rates at the system level (appropriate for the system slide-rule model) will be developed.

A simple expression for the number of failures per system operating hour of a component is the following:

$$D_i = N_i d_i / MTBF_i,$$

where D_i is the demand of the ith component, N_i is the number of components in the subsystem (where the subsystem is the next higher aggregation level), d_i is the ratio of component operating hours to subsystem operating hours, and $MTBF_i$ is the mean time between failure of the component.

The hourly manpower requirement for the ith component, m , is expressed by:

$$m_i = D_i(MTRR_i + R_i MTTR_i),$$

where $MTRR_i$ is the mean time to remove and replace the ith component, $MTTR_i$ is the mean time to repair, and R_i a binary switch (as before) set to 0 if the component is coded discard (or non-organizational repair), otherwise it is set to 1.

Going to the next indenture level, the failure rate of the assembly is the sum of the failure rates of its components - each time a component fails, the entire assembly must be replaced. If the assembly is coded repair, additional maintenance time is required to remove and replace the components of the assembly. The hourly corrective maintenance manpower requirement for the jth assembly, m_j, therefore, is given by:

$$m_j = \left[MTRR_j \sum_{i=1}^{w_j} D_i + R_j \sum_{i=1}^{w_j} m_i\right] N_j d_j,$$

where w_j is the number of different components in the jth assembly, and $MTRR_j$, R_j, d_j and N_j are defined as before, only this time pertaining to the assemblies.

The total hourly system maintenance requirement is the sum of the maintenance requirements for all assemblies, plus the system-level maintenance requirement, including preventative and facility maintenance:

$$m = m_s + \sum_{j=1}^{N} m_j,$$

where m_s is the hourly system level maintenance requirement and N the number of unique assemblies in the system.

Once m has been determined, it should be inflated by a

productive allowance factor, which is "a percentage allowance applied to basic productive work requirements to reflect those delays arising from fatigue, environmental effects, personal needs and unavoidable interruptions which serve to increase the time required for work accomplishment."* The size of the productive allowance factor varies according to the type of work; industrial experience indicates that it is never less than 10% under any circumstances, and may be two or three times larger.

The hourly demand for maintenance manpower is converted to a weekly demand by multiplying m by the average number of weekly system operating hours expected during a deployment period.

In order to convert the total weekly maintenance man-hour requirement into a requirement expressed in terms of men, or billets, the weekly man-hour requirement is divided by the number of weekly available hours for assigned work for maintenance personnel, which is the number of hours in a week less hours spent on sleep, messing, personal needs, free time, service diversions (e.g., quarters, general drills), and training. If, for example, the average number of available hours during the assigned work week for a non-watchstander is 66 hours, the total maintenance manpower requirement expressed in billets is obtained by dividing the weekly maintenance man-hour requirement by 66.

A note is in order about a further time element that figures into the total manning requirement. Bearing a close relationship to the

*10-P, ibid., p. IV-1. Other services use a "labor utilization rate," equal to one minus the productive allowance factor. It therefore expresses the proportion of duty hours actually delivered in productive labor.

design and complexity of a new system and excluded from all other elements of time accounting is a variable time requirement that might be termed "technical preparation" time. We refer here to a relatively large block of time devoted to the general study of his system by a repair technician. No formal measure or nomenclature of which we are aware recognizes this requirement. Beyond its importance simply as a large consumer of labor time, the phenomenon is also very interesting because it can be expected to vary inversly with actual time spent repairing. In other words, to maintain his skill at a certain level, the technician must spend a specific amount of time with it - whether repairing it or simply studying it. This may have very important and counter intuitive implications for high reliability design.

To summarize the preceeding paragraphs, let M be the total maintenance manpower requirement in billets (this is the same M which is used as input to the manpower cost equation). The value of M is equal to mpd/F, where m is the hourly system maintenance manpower requirement, p is the productive allowance factor, d is the average number of system operating hours in a week, and F is the average number of weekly available work hours for maintenance personnel.*

The determination of the value of M can become computationally much more complex, especially when more sophisticated level of repair analysis is incorporated into the design process, requiring that values of M be computed for organizational, intermediate, and depot repair

*Of course, d and F do not necessarily have to be defined in terms of weeks. Any unit of time is appropriate provided the definitions are consistant.

facilities. Examples of computational techniques used in these cases are presented in Chapters 4, 5 and 6. However, in all cases the basic structure behind the methodology used to determine M is the one presented above.

Determining the Demand for Operator Manpower

The process of determining demand for system operators is quite different from that for maintenance personnel. There are two major distinctions between the two cases:

1. Maintenance manpower requirements are based on average demand. This is not the case for operator manpower requirements, which require a consideration of both average and peak demand.

2. Maintenance work by its very nature requires 100% attention to the task; it is not reasonable to expect maintainers to do anything else while they are working on the repair of a failed system. Operators, however often man two or more systems simultaneously, in which case it is difficult, both conceptually and practically, to determine just what the demand of each system actually is.

These two distinctions will be dealt with in turn.

The main reason that maintenance manpower can be based on average demand is that maintenance activities can be accomplished at the technician's convenience. Thus, it is really not important if, for example, a month's worth of failures all occur within a few days. The technician merely replaces the failed parts and then repairs them over a period of a month in either case. [This assumption is reasonable because, in general, total removal and replacement time is so small that it is an acceptable approximation to state, for example, that a four man-hour daily maintenance requirement can be handled by a single technician, even if system components are failing on a random basis for

24 hours a day.] Operator manning requirements, however, cannot be based solely on the average daily (or weekly) demand for operator time. As an example, set d = 8 hours. Operator manning requirements and utilization would be completely different if the system did in fact operate exactly eight hours a day (and no more) every day, than if it operated 24 hours a day during one-third of the ship's deployment period.

Operating personnel, therefore, must be manned according to peak demand. They are utilized according to average demand. The difference between the two can lead to significant overpayment costs for underutilized labor. (The example in which the system operates 24 hours a day during peak periods totalling one-third of the deployment period could result in assignment of new personnel to a platform who spend <u>two-thirds</u> of their time on non-prime activities.)

To help determine the demand for operator billets, we present the concept of expected duration of operation (EDO). This is the expected value of the longest period of "continuous" (we will define "continuous" more precisely below) operation of the system. EDO is defined for a number of different readiness conditions.* Each readiness condition can be characterized by a maximum expected time for non-stop operational duty (MO), a minimum rest period between operating watches (MR), and a maximum expected duration of crew endurance during the readiness conditions (ME). For example, for battle readiness - limited action, MO=20 hours, MR = 4 hours, and ME = 10 days. System operation

*10-P lists five conditions of manning readiness: battle readiness, battle readiness - limited action, wartime cruising readiness, peacetime cruising readiness, and in-port readiness. Ibid., p. II-16,17.

is considered "continuous" if the expected duration of system down times is less than MR for the given readiness condition. (An additional value for required rest periods during operating duty can also be included.)

An algorithm for determining total operating manning requirements, therefore, is the following. First, the value of EDO is computed for each readiness condition as a function of the system operating profile during that condition and MR.

Then the number of operating personnel required under each operating condition is computed as a function of EDO, MR and ME. The actual function could be quite complex, including other factors and Naval personnel policies. The moderately simple algorithm below is presented as an example of a possible function.

$$\text{required operating billets under readiness condition} = \begin{cases} I(EDO/MO) \text{ if } EDO \leqslant 24 \text{ hours} \\ I(24/MO) \text{ if } 24 < EDO \leqslant ME \\ \text{if } EDO > ME \text{ calculate operating billet requirement for next lower readiness level} \end{cases}$$

The required number of operating billets (equivalently, the number of personnel who must receive operator training) is the maximum of the required number of operating billets for all readiness conditions (i.e., peak demand billets).

Thus, operator manning levels are determined by peak demand. However, operator utilization, and hence wage or opportunity cost, is determined by average demand. Let m be the average weekly manhour requirement for system operators, and F the available weekly work hours for system operators. As was the case of maintenance personnel, the

average billet requirement for system operators is given by m/F. There is an additional consideration for system operators, however. The personnel may be operating other systems simultaneously with the new system, and if so, it is incorrect to state that total system operator demand is m/F. Rather, the value should be reduced by a factor which reflects the fraction of the operator's total workload represented by the system. This factor is called a; the value of total operator demand (the value of M input to the cost equation) is therefore am/F.

There are definite problems involved in determining values for a. Obviously, the choice is important: the difference between a=.2 and a=.5 can be nearly 20 million dollars for a widely deployed system with a ten year life cycle. One method for making rough approximations of a (suitable to the early design stages) is to assign it a value equal to the reciprocal of the total number of systems the operator is expected to run simultaneously.* If there is no operator requirement (the system is entirely automatic), then a is set equal to zero.**

*This has the virtue of always charging the full direct wage cost even if an operator is underutilized with regard to attention capacity. It has the drawback of removing the concept of a from the range of design policy variables.

**There is hope for more accurate and sophisticated techniques for measuring values of a. The 28 August 1978 issue of Aviation Week and Space Technology reports on progress in measuring mental workload for aircraft pilots (a measure similar in nature but even more complex than a). Research project leader, Dr. Deanna S. Kitay, states confidently that "mental workload can be measured." If this proves feasible, measures of mental workload can be used to determine total operator manpower requirements for systems based both on system workload demands and total existing mental workloads of on-board personnel. Threshold values for workload could be defined; exceeding these thresholds would require that additional personnel be assigned to the system.

To summarize this section, average manpower demand for operators and maintenance personel has been determined. For maintenance personnel, this requirement is computed from the failure rates, MTTR, MTRR and level of repair operations of the subelements of the system; for operators the demand is determined from the average operating hours of the system and the demands of the system on ooperator workload. Personnel manning assignments (the number of personnel to receive training) are determined directly from the average demand for maintenance personnel; for operators, a second set of algorithms based on peak demand is required.

Drawing From the Manpower Pools

Once manpower demand has been determined, the next issue to be resolved is: where are the personnel going to come from? Recall that there are three manpower pools from which it is possible to draw personnel: AN, the pool of trained manpower; AG, the pool of on-board general labor; and AS, the pool of general personnel available from within the Navy. In this section, the least-cost algorithms for drawing from the manpower pools are developed.

Whenever possible, the manpower requirement, M, should be met from within the AN pool, for doing so avoids all "A" school costs, overpayment costs due to underutilization (in fact, the AN pool is reduced), and most "other" costs. Thus, whenever $M \leq AN$, the personnel utilized from each pool are: $An=M$, $Ag=As=0$. The situation becomes somewhat more complex when $M>AN$, requiring that personnel be drawn from either the AG or AS pools, or both. In the initial development of the manpower cost equations, it was noted that the costs of drawing from the

AG and AS pools are identical, except that the AS pool has a much higher value for "other" costs. Thus, it is always preferable to draw from the AG pool before the AS pool. A simple algorithm for drawing from the manpower pools would be to first draw from the AN pool until it is exhausted, then draw from the AG pool, and finally, only draw from the AS pool when no other personnel are available. There is, however, one important exception to the rule. This exception is best explained using two specific examples: let AN = 2.5; in the first case set M = 3.7, and in the second case set M = 3.2. In both cases, two whole men are drawn from the AN pool. The question is: should the fractional man (.5 in AN) be used as well? In the first case 2 men from AG would have to be trained whether the .5 man from the AN pool were used or not: I(1.7) = I(1.2) = 2. By not using that fractional man, training cost can be reduced by one man's attendance at "C" school. The wage costs are the same either way, as are the additions to the AN pool. Thus, in the case that AN > M and FRAC(AN) < FRAC(M) (provided M is not an integer) it is always cheaper <u>not</u> to utilize the fractional portion of the AN pool, but rather to draw as many whole personnel as possible from the AN pool and meet the remaining manpower requirement from the AG or even AS pools. In the second case, where AN = 2.5 and M = 3.2, one can and should meet the fractional part of the demand from the AN pool, avoiding "A" school and "other" costs for additional personnel,

in addition to eliminating additions to the AN pool.

The algorithms for drawing from the manpower pools can be summarized as follows. First, draw from the AN pool until all whole personnel have been removed. If the fractional part of the remaining demand can be met from the AN pool, then do so, otherwise begin drawing from the AG pool. Draw from the AS pool only when the AG pool has been exhaused. Mathematically, these algorithms are expressed as follows:

$$\mathrm{An} = \begin{cases} \mathrm{M} & \mathrm{M} \leq \mathrm{AN} \\ \mathrm{AN} & \mathrm{M} > \mathrm{AN} \text{ and } 0 < \mathrm{FRAC(M)} < \mathrm{FRAC(AN)} \\ \mathrm{INT(AN)} & \text{otherwise} \end{cases}$$

$$\mathrm{Ag} = \mathrm{MIN(M\text{-}An,AG)}$$

$$\mathrm{As} = \mathrm{M - An - Ag.}$$

These algorithms are incorporated into the manpower cost equations of the model systems.

The manpower drawing algorithms have in them an implicit assumption of perfect cross-utilization of personnel. That is, manpower assignments and personnel available can be shuffled so as to exactly meet manpower requirements. Suppose, for example, that M=.7 and AN=1.0, where the 1.0 man in the AN pool consists of the sum of the underutilized time of three different men. Cross-utilization means that the assignments of three people can be shuffled so that one man can meet the requirement. This assumption is reasonable for maintenance personnel, since most maintenance activities can be accomplished at the technician's convenience. Rearranging maintenance schedules and shifting duties is, therefore, not too difficult an administrative task. The assumption of perfect cross-utilization is somewhat less valid for

system operators, however, due to the simple requirement that operators be physically present at their watch station during system operations. For example, an operator requirement of M=1 could not necessarily be met from an AN pool where AN=1.0 if the system requires one full-time, fully occupied operator and AN consists of the available mental workload of 10 different operators, each working full-time at 90% capacity.

Thus, while the assumption of perfect cross utilization is generally a reasonable one,* designers should always have the option of overriding values computed in the models. This would be done whenever information is available on the actual operating environment of the system. This, of course, is true for <u>all</u> values computed by <u>any</u> cost model.

<u>Billet Costs (Bn and Bg)</u>

The wage cost of personnel is determined using the Billet Cost Model (BCM), which computes the total cost of personnel, including base pay, allowances, vacations, travel, training, retirement contributions, and so on.

One of the more important potential cost trade-off items is hardware design versus personnel skill levels. This trade-off is implicitly incorporated in the choice of billet cost input to the model systems. The choice should be determined by the system designer; once determined, billet cost is not a policy variable for lower level designers, although input from lower level design decisions could

*According to 10-P, p. V-8, calculated optimum manning based on the assumption of perfect and complete cross utilization is normally within 5% of actual documented requirements.

ultimately cause a system-level design alteration resulting in changes in personnel requirements and skill-levels.

In using the Billet Cost Model, one conceptual difficulty arises. Estimates in the BCM include a training cost component. Since training cost is heavily dependent on design options, it is inappropriate for the designer to use an implicit value based on existing, albeit similar, equipment. Therefore, the program office (which is responsible for providing design teams with values for Bn and Bg) must take care to include only basic training in Bg and basic training plus "A" school in Bn.*

Other Costs (Z and Zs)

There are two basic types of "other" costs: security clearances and the costs associated with adding new personnel to a platform. The second are personnel support costs, including administrative, command, supply and medical costs, and ship alteration costs.

Recall that a distinction was made between other costs for existing personnel and for new personnel. These costs were called Z and Zs, respectively. The first cost category, security clearances, is applicable to both existing and new personnel. Note that security clearance costs for existing personnel are almost certainly less than or equal to those for new personnel.

Support costs are the cost of increases in the support

*It is not clear at this time if such adjustments to the BCM published data are easily acomplished or even feasible.

structure which arise as a direct result of the introduction of the new equipment. There are two ways in which these costs can be treated. A simple method, recommended for use in the linked and graded model system, is to use a value, provided by the Navy program office, which represents the average cost of additional support per man, which is then multiplied by the number of new personnel added to the platform as determined by the manpower pool drawing algorithms. In more advanced models, however, support costs can be derived in exactly the same manner as were direct manpower costs. Just as the failure rate and mean time to repair of a system can be used to determine the maintenance manpower requirement, the direct manpower requirement determines the support requirement. Support personnel are drawn from their own manpower pools, and percentages of their cost allocated either to the system or to general labor. Tertiary effects - support of the support personnel - can be derived in a similar manner (this would only be necessary if the original system is of sufficient proportions that these costs are significant).

The Operator-Maintainer

A manpower planning option which can be explored by the system designer is to have the same personnel perform both maintenance and operating duties. The primary advantage of this option is that it can sharply reduce the number of personnel who must receive training and/or be added to the ship's complement. Total personnel utilization can similarly be increased. The operator-maintainer option, however, can be disadvantageous when there is a wide disparity between the skill and training levels required for the two separate tasks. Imagine, for

example, a system which is extremely simple to operate and extremely difficult to repair. It may not be cost-effective to require that a highly trained and skilled (and hence, expensive) maintenance technician devote most of his time to the operation of the system when that duty could be filled by much less skilled personnel, freeing the maintenance technician to use his time more effectively on other maintenance duties.

The incorporation of the operator-maintainer option into the manpower cost equation can be accomplished by computing the average and peak demands for operators and maintenance personnel, adding them together, and then using them in the cost equation.

3.3 SUMMARY

A rather lengthy exposition was requird to develop the manpower cost equations and their input values. In addition, in many places it was necessary to make distinctions between maintenance personnel and operators. In this section, therefore, the manpower cost equation is briefly summarized.

Manpower Cost = Wage + Training + Other Costs

Wage = MBg + A(Bn-Bg)

M is the average demand for manpower billets for the system. For maintenance personnel, M is determined from the MTBF, MTTR, LOR, etc. of the components of the system. For operators, M is determined by average system operating hours and system demands on operator mental workload.

Bg is the billet cost for general labor personnel. There is an implicit assumption in the cost equations that personnel spend their non-prime equipment time on general labor, whose value is reflected by Bg.

Bn is the billet cost for trained personnel who have already completed "A" school. En is greater than Bg because the discounted present value of trained personnel is greater than untrained personnel.

A is the number of personnel to receive "A" school training. A = I(Ag)+I(As). Ag, As and An are the number of personnel utilized from the three manpower pools: AG, the on-board pool; AS, the Navy-wide general pool; and AN, the on-board trained pool. The least cost algorithms for drawing from the manpower pools are the following:

$$An = \begin{cases} M' & M' \leqslant AN \\ AN & M' > AN \text{ and } 0 < FRAC(M') < FRAC(AN) \\ INT(AN) & \text{otherwise} \end{cases}$$

$$Ag = MIN(M'-An, AG)$$

$$As = M'-An-Ag$$

For maintenance personnel, $M'=M$, the average demand. For operators, M' is the peak manning demand, determined by computing the operator demand (based on expected maximum length of continuous system operation) for a number of readiness conditions and then taking the maximum value. The algorithms assume perfect and complete cross-utilization of personnel. This assumption is reasonable for maintenance personnel, but somewhat less generally valid for operators.

Training = DTc + ATa

D is the number of personnel to attend "C" school. $D = I(An)+I(Ag)+I(As)$. For maintenance personnel, $D=I(M)$. For operators, $D=I(M')$.

Tc is the unit course cost for "C" school. Tc for maintenance personnel is determined by aggregating course requirements (which vary as a function of LOR for SRAs, WRAs and the system). Tc for operators is determined by aggregating operator course requirements for subsystems and the system.

Ta is the unit course cost for "A" school. This cost is, in most cases, provided for the designer by the Navy program office, although the option of eliminating or modifying the course can be explored by the designer.

Other Costs = BZ + I(As)Zs

B is the number of on-board personnel utilized by the system. $B = I(An) + I(Ag)$.

Z is the cost of obtaining security clearances and other additional costs required for on board personnel to man the system.

Zs is the total cost of adding new personnel, I(As), to the platform. Zs includes all administrative, support, supply and possible ship alteration or construction.

4.0 MODELLING IN THE CONCEPTUAL PHASE

This is the first of three chapters in which examples of models and manpower equations, each keyed to a specific phase of the WSAP, are presented. The structure of this and the following two chapters will be the following. First, a brief description of the design phase is presented, including a discussion of the information, decision, trade-off and model requirements associated with that phase. Then, detailed explanations of the structures of the cost models used in the phases are presented. Finally, examples of manpower cost equations appropriate to the cost models are developed. It must be emphasized that the structures of the model systems and the cost equations presented are only examples - guidelines for constructing new model systems appropriate to individual design projects.

4.1 DESCRIPTION OF THE CONCEPTUAL PHASE

The Conceptual Phase begins with a Science and Technology Objective (STO) paper, which is prepared by DRDT&E for each warfare area and updated annually. The STO describes, in broad terms, the Navy role and objectives anticipated in a particular warfare area over the next 10-20 years. NAVMAT analyzes the STO's and documents possible solutions in Advanced System Concepts (ASC). These documents contain a technical approach, cost estimates, and a discussion of operational effectiveness, and critical technologies.

The next step is the Operational Requirement, Development Proposal, and Navy Development Concept papers. These papers list the operational need, the concept and capabilities required, the performance goals and cost objectives, program alternatives, and conceptual phase milestones and thresholds.

Once conceptualization has reached the point of specific system design alternatives the linked and graded model system should be introduced. At this point, a Project Manager is assigned and system conceptual work begun within Navy funding limits. This is when the system slide-rule model is used.

First, major system engineering parameters are developed for a series of alternative systems. Information requirements at this stage include: manpower, training and skill level constraints based on CNO policy decisions; the number of systems to acquire; the number of Navy personnel to operate the system; and the number of personnel already

available for operation and support on the proposed platform. The system slide-rule model is used to conduct trade-offs between alternative systems and variations of each alternative. The model will determine initial manpower and training requirements for operation, maintenance and support, special training requirements, a preliminary maintenance and ILS concept including the military/civilian maintenance manpower mix, and initial estimates of total acquisition operation, support, and life cycle costs. The system analyst will be required to provide rough estimates of such costs as hardware production, R&D, support equipment, MILCON, and so on. Depending on the acquisition category, the preferrd alternative is chosen by CNO after CEB review, and by SECNAV after DNSARC review. The program is then submitted to DSARC I, which deals with the following issues: Does a need for the system exist and are the following program issues defined; special logistics problems, program objectives, program plans, performance parameters, areas of major risk, system alternatives and acquisition strategies.

If the system is approved, it continues to Phase II, Validation.

4.2 THE SYSTEM SLIDE-RULE MODEL

The system slide-rule model is used by the senior system designer during the earliest design stages of the Conceptual Phase to compare the relative costs of alternative system designs for meeting conceptual requirements. The model considers the system as a whole, making relatively gross assumptions about the nature of the subelements of the system. For example, one possible assumption is to state that the failure rate and unit production costs of the system are uniformly distributed over all subsystems.* In later models, these assumptions are replaced by real data on subsystem designs.

To get started, the system designer collects a data set of descriptive variables. The data set is small, approximately 20-30 variables, and includes both variables characterizing specific system design alternatives and variables characterizing the operating environment in which the system will be deployed. Once the initial data set has been collected (for design variables this can be acomplished in a matter of minutes), the cost impact of alternative approaches can be examined by altering the values of the relevant input variables.

Rough preliminary maintenance concepts can be achieved by

*Note that this particular assumption is appropriate to the design of a system or equipment which is to be added to a platform. Models for platform design would require a different set of assumptions. Most of the examples presented in these guidelines are keyed to equipment rather than platform design. The reasons for this are clear: a platform is the aggregation of the systems it contains; the bulk of the platform design work is the design of its passenger systems.

assigning level of repair options to varying percentages of the number of assemblies which make up the system. Manpower wage and training costs are linked to system parameters, facilitating hardware/manpower trade-offs. The system slide-rule model aids the senior system designer in choosing the overall system approach by allowing him to see immediately the rough cost implications of alternative design aproaches, enabling him to find the most cost effective design paths in the most efficient manner.

4.3 MANPOWER COST EQUATIONS IN THE SYSTEM SLIDE-RULE MODEL

The same basic manpower cost equation is used in all cost models. This equation, summarized in Section 3.3, is short and simple enough to be implemented on almost any programmable calculator. However, if machine limitations cause programming problems, a second, slightly shorter but mathematically equivalent cost equation can be used. This equation is based on functions which eliminate the need for explicit consideration of the values of An, Ag, and As. However, the price payed for this compression is that the equation becomes a mathematical formalism which to a large extent masks reality. The equation is the following:

$$\text{Manpower cost} = MBg + A(Bn-Bg) + (M-N)Z + NZs + I'(M)Tc + ATa,$$

where

$$I'(x) = \begin{cases} I(x) & x > 0 \\ 0 & x \leq 0 \end{cases}$$

$$N = I'(M-F-AG)$$

$$F = \begin{cases} AN & 0 < FRAC(M) < FRAC(AN) \\ INT(AN) & \text{otherwise} \end{cases}$$

$$A = N + I'(M-N-F).$$

This equation has the drawback that it makes it difficult for the user to distinguish between average and peak manpower demand.

The difference between the manpower cost equations used in the various model systems, therefore, is not the cost equation itself, but the manner in which the input values to the equation are generated. The

system slide-rule model, being the first and simplest of the model systems, uses a rather simple set of equations to derive the input values to the cost equation. A sample set of equations is presented below.

Average demand for operator labor:

$$Mo = QOda/F,$$

where Q is the number of systems deployed on the ship, O is the number of personnel required to operate the system, d is average system weekly operating hours, a is the system workload factor, and F is the average available weekly duty hours for watch standers.

Peak demand for operator labor:

$$Mo' = Mo.$$

[The assumption that average demand for operators is the same as peak demand may be a reasonable simplifying factor in early system design for many types of systems. Note that this assumption fits in well with the use of the compacted form of the manpower cost equation. The assumption will be dropped in later model systems.]

Average demand for maintenance labor:

$$M = [d(MTRR+rMTTR)/MTBF + PM]Q/uF,$$

where MTBF is the mean time between failure of the system, MTRR is the average time to remove and replace a failed assembly of the system, r is the fraction of assemblies of the system coded repair, MTTR is the mean time to repair a failed assembly, PM is the weekly preventative

maintenance requirement of the system, and u is the productive allowance factor.

The remaining input variables to the manpower cost equation, Bg, Bn, Tc, Ta, Z and Zs, are all estimated by the senior system analyst exogenously to the system slide-rule model and are input directly to the model.

5.0 MODELLING IN THE VALIDATION PHASE

5.1 Description of the Validation Phase

The first step of the Validation Phase is the development of the Project Master Plan, which provides uniform guidance for work planning and scheduling. RFP's are then issued, contractors selected, and the equipment is studied, designed, built and tested.

At this point the contractor uses the slide-rule aggregation model system. The process begins at the top, with the system designer specifying technical requirements for the major systems. Subsystems are assigned to subsystem designers, who in turn assign component designs. Now the process of interactive design trade-off analysis begins. On the basis of technical and cost information flowing up from the more detailed levels, the system designer sends down instructions causing changes in design direction. The system is initialized using the cost information obtained during the Conceptual Phase. This includes: the number of systems, initial estimates of manpower, training and skill levels, initial estimates of LCC, initial engineering design parameters for each major subsystem, billet costs, historical data (e.g., number of men available), mission profile and environmental profile. Trade-offs conducted at the system, subsystem and component level include: reliability, maintainability, research and development cost, hardware cost, spares cost, logistic support cost, manpower cost (operational, maintenance, support), training costs and other training data, including skill levels, specialized training courses, technical training equipment, training devices, and construction costs.

The Validation Phase ends with DSARC II, which deals with the following issues: the need for the system in consideration of threat, system alternatives, and special logistic needs; estimates of development costs; preliminary estimates of life cycle costs; potential benefits in the context of overall DoD strategy and fiscal guidance; development risks; and finally, whether the plan for full-scale development is realistic.

5.2 THE SLIDE-RULE AGGREGATION MODEL SYSTEM

In order to achieve the required simplicity of use and to mesh with the limited detailed knowledge of system structure that is available during the earliest stages of system conceptualization, many admittedly arbitrary assumptions must be made about the structure of the system. As the initial system design is fleshed out, however, these assumptions will no longer be valid or necessary. A second model system is needed to handle the rapidly increasing amount of real data on the details of the system structure. This system consist. of three linked slide-rule models at three levels of design aggregation; component, subsystem and system.*

The system designer used the system slide-rule model to help determine the overall system approach. His next task is to break down the system into subsystems, the design of which is made the responsibility of individual designers, who in turn break down the subsystem into components, assigning them to detail designers.

The structure of the slide-rule aggregation model system parallels this hierarchical process of design. The system designer trades in his original slide-rule model for a new version, the slide-rule system aggregation model. This model is similar in mathematical structure to the original model, but rather than making general assumptions about the character of the subsystems, the new model

*There is nothing canonical about three levels of aggregation. The following discussion will make it clear that it is a simple matter to add or delete aggregation levels. Nor is the hierarchical division into components, subsystems, and systems mandatory. The choice of aggregation structure will depend on the characteristics of the individual design.

builds up the system as the aggregation of individual subsystems.

As soon as he has blocked out an initial system approach, the system designer creates a set of "dummy" subsystems, each characterized by the technical and cost goals he envisions for the actual subsystem. The system aggregation model accepts input data on each subsystem, in addition to specific system-level data, and adds them all together to estimate total system cost. The designer compares alternative system approaches by creating new subsystems and reconfiguring them to build the new system. Once the system designer decides on an initial configuration, he records the variables characterizing cost and performance goals of the "dummy" subsystems, as well as additional variables characterizing the operating environment.

Each subsystem designer is equipped with a subsystem slide-rule aggregation model, identical in stucture to the system aggregation model, but keyed to the design of subsystems rather than entire systems. The subsystem designers use the data sets generated earlier as their starting points. The task of subsystem design resolves itself to one in which component elements of the subsystem are fully described in a series of data sets analogous to the subsystem data set, but descriptive of each component. These, passed down to detailed designers, represent initial design goal allocations.

The detail designers are at the base of the hierarchical structure of design. Each has a component slide-rule model. He uses data which characterize the design of his component, including such elements as MTTR, MTBF, projectd unit cost, and so on. As he works on his design, he replaces the straw-man description of

his component provided by the subsystem designer with real data on his design. The designer uses his model to produce estimates of the cost impact of alternative approaches. Possibly he won't be able to meet the cost and technical goals implicit in the initial data, or perhaps he can surpass them. Different level of repair alternatives would be available in the component model, allowing the detail designer to optimize his design to the appropriate repair option or to the discard mode. Once the component designer has completed his work, he passes revised data back up to the subsystem designer.

The subsystem designer is now able to replace the dummy components in his subsystem with real data for each component. Gradually, all the dummy components in the subsystem will be replaced by data sets characterizing real components. Based on the results of subsystem and component-level trade-offs, the subsystem designer modifies the cost and performance goals for the components and relays the modification to the component designers. Periodically, each subsystem designer sends his revised data set to the system designer.

The relationship between the system and subsystem designers is the same as that betwen the subsystem and detail designer.

The structure of the slide-rule aggregation model system is presented in Figure 5.1. The system is readily adaptable to both top-down and bottom-up design.*

*In top-down design, system configuration is completely worked out first; the design then proceeds down the aggregation levels. In bottom-up design the process is reversed. Top-down designs generally lead to more efficient systems, but can become hung up whenever there is uncertainty as to the resolution of detail design problems, and destroyed completely if details assumed by system designers to be trivial turn out to be insoluable.

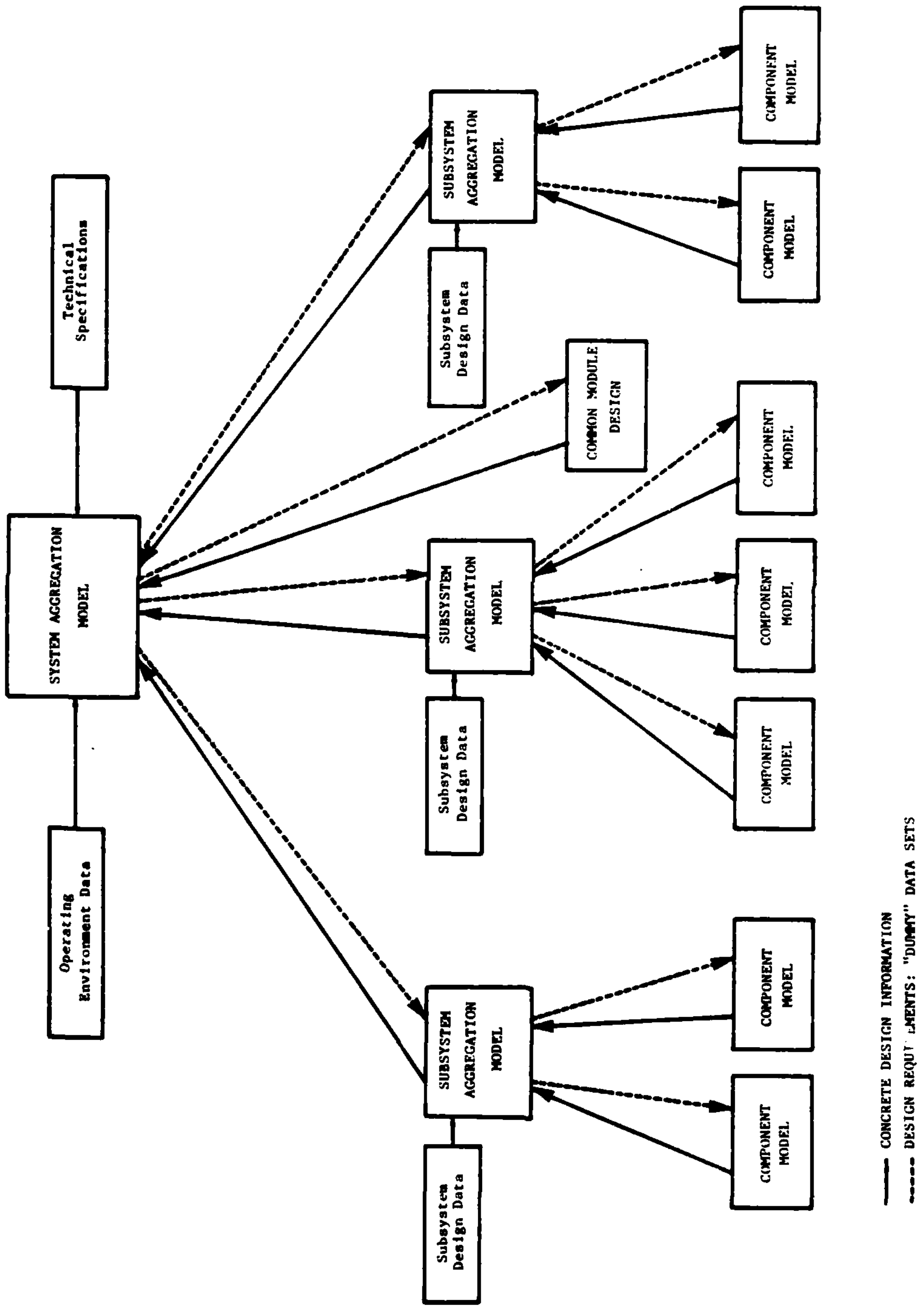

Figure 5.1 Slide-Rule Aggregation Model System

5.3 MANPOWER EQUATIONS IN THE SLIDE-RULE AGGREGATION MODEL SYSTEM

In Section 3.2 the general methods for determining input values to the manpower cost equation were developed for a three indenture level model system. Although it was not stated explicitly at the time, the methods presented there are appropriate to a slide-rule type of aggregation model system. What we propose to do now is to present the equations again quickly and without commment, and then give examples of how these equations can be expanded to deal with more detailed issues. Specifically, we will show how the maintenance wage and "C" school demand equation can be modified to incorporate level of repair analysis.

The equations for the manpower input variables to the slide-rule aggregation model system cost equation are summarized in Table 5.1. Note that there is no operator manpower requirement below the system level, and no operator training requirement below the subsystem level.

An important addition to the equations of the model system is the incorporation of level of repair alternatives for the components and assemblies of the system. Doing so will have a strong impact on maintenance manpower and training requirements. We now show how the maintenance demand equations presented in Table 5.1 can be adapted to include a consideration of three repair alternatives, local repair, intermediate repair and depot repair, as well as the discard option.

To get started, let us define some terms. Let LR, IR, and DR respectively be binary switches set to 1 if an element is coded local, intermediate, or depot repair, otherwise they are set to zero. Let MTRR be the mean time to remove and replace an element, and TRR be the training course length required to learn how to do so. Similarly,

Component Model

$$Tc(m)_i = TRR_i + Tr_i R_i$$

$$D_i = N_i d_i / MTBF_i$$

$$m_i = D_i(MTRR_i + R_i MTTR_i)$$

Subsystem Model

$$Tc(o)_j = Tc(o)$$

$$Tc(m)_j = TRR_j + \sum_{i=1}^{w_j} Tc(m)_i$$

$$m_j = (MTRR_j \sum_{i=1}^{w_j} D_i + R_j \sum_{i=1}^{w_j} m_i) N_j d_j$$

System Model

$$Tc(o) = Tc(o)_s + \sum_{j=1}^{N} Tc(o)_j$$

$$Tc(m) = Tc(m)_s + \sum_{j=1}^{N} Tc(m)_j$$

$$M(o) = dOa/F$$

$$M'(o) = \begin{cases} I(EDO/MO & EDO \le 24 \text{ hr} \\ I(24/MO & EDO > 24 \text{ hr} \end{cases}$$

$$M(m) = (m_s + \sum_{j=1}^{N} m_j) pd/F$$

Table 5.1 Sample input value equations to Slide-Rule Aggregation Model System Manpower Cost Equation

define MTTR and TTR as the mean time to repair and its associated training requirement. These values of MTTR and MTRR could vary for different maintenance facilities. Thus, we have LMTRR, IMTRR, DMTRR, LMTTR, IMTTR, and DMTTR. We assume that the training courses for each maintenance facility are equivalent, although there is no difficulty in introducing LTTR, LTRR, ITRR, and so on. Let LM, IM, and DM respectively be the maintenance manpower requirement at the local, intermediate, and depot repair facilities, and LT, IT, and DT respectively be the total training requirement. Finally, let i be the component index, and j the subsystem index. With these definitions in hand, we turn to the maintenance manpower and training requirements equations for the three models of the slide-rule aggregation model system: component, subsystem and system.

Component Model

The hourly demand of an elements does not depend on its level of repair:

$$D_{ij} = N_j P_j Q_{ij} \; P_{ij}/MTBF_i,$$

where N_j is the number of jth assemblies in the system, P_j is the ratio of assembly operating time to system operating time, Q_{ij} is the number of ith components in the jth assembly, P_{ij} is the ratio of component to assembly operating time, and $MTBF_i$ is the mean time between failures of the ith component.

The local manpower demand and training requirement is a function of the level of repair code both of the component and of the assembly

containing it:

$$LM_{ij} = LR_j D_{ij}(MTRR_{ij} + LR_{ij}LMTTR_i),$$

$$LT_{ij} = LR_j TRR_{ij} + LR_{ij}TR_i.$$

Manpower and training requirements at the intermediate repair facility are slightly more complex to determine than at the local level, because there are two ways in which the component might reach the intermediate facility: if the assembly containing the component is coded local repair and the component intermediate repair, or if both the assembly and the component are coded intermediate repair.

$$IM_{ij} = D_{ij}[LR_j IR_{ij} IMTTR_i + IR_j(IMTRR_{ij} + IR_{ij}IMTTR_i)]$$

$$IT_{ij} = LR_j IR_{ij} TTR_i + IR_j(TRR_{ij} + IR_{ij}TTR_i).$$

The manpower and training requirements at the depot are yet more complex because there are three ways in which the component can reach the depot, depending on whether the assembly containing it is coded local, intermediate, or depot repair:

$$DM_{ij} = D_{ij}[(LR_j + IR_j)DR_{ij}DMTTR_i + DR_j(DMTRR_{ij} + DR_{ij}DMTTR_i)]$$

$$DT_{ij} = (LR_j + IR_j)DR_{ij}TTR_i + DR_j(TRR_{ij} + DR_{ij}TTR_i).$$

Assembly Model

The equations for the maintenance manpower and training requirements of the assembly model are much simpler than those for the component model. The local manpower requirement consists of two parts. First, the assembly must be removed and replaced each time one of its

components fails, and second, repair work must be accomplished on all components in the assembly coded local repair:

$$LM_j = MTRR_j \sum_i D_{ij} + \sum_i LM_{ij}.$$

Training to remove and replace the assembly is required at the local level. Additional training is required for any components coded local repair:

$$LT_j = TRR_j + \sum_i LT_{ij}.$$

The intermediate manpower requirement for an assembly is simply the sum of the intermediate requirements for its components. The same is true for intermediate training and for the depot repair facility:

$$IM_j = \sum_i IM_{ij}$$

$$IT_j = \sum_i IT_{ij}$$

$$DM_j = \sum_i DM_{ij}$$

$$DT_j = \sum_i DT_{ij}.$$

System Model

System level manpower requirements are determined by summing the man-hour requirements for all the subsystems and then converting these requirements into billets. At the local facility there is an additional maintenance requirement, MS, for preventative and facility maintenance. In addition, local maintenance technicians receive a system-level training course not required at the other repair

facilities:

$$LM = (MS + \sum_i LM_j)d/(LU \cdot LF)$$

$$LT = TS + \sum_i LT_j$$

$$IM = (\sum_i IM_j)d/(IU \cdot IF)$$

$$IT = \sum_i IT_j$$

$$DM = (\sum_i DM_j)d/(IU \cdot IF)$$

$$DT = \sum_i DT_j,$$

where d is average weekly system operating hours, LU, IU, and DU are respectively the local, intermediate, and depot production allowance factors, and LF, IF and DF respectively are the local, intermediate, and depot available weekly work hours.

Total "C" school maintenance training costs at each facility are therefore given by:

Local training	=	$I(LM) \cdot LT$
Intermediate training	=	$I(IM) \cdot IT$
Depot training	=	$I(DM) \cdot DT$.

6.0 MODELLING IN THE FULL-SCALE DEVELOPMENT PHASE

6.1 Description of the Full-Scale Development Phase

During full-scale development the final form of a new system is set. Finer issues must be dealt with, and the full-scale system aggregation model is used to handle them. Information requirements now include the following: manpower requirements by occupational group, mission sponsor, warfare sponsor and skill level; training requirements, including training courses, instructors and students, technical training equipment, and text material; personnel requirements, including billet analysis, inventory projections, and promotion and recruitment projections; revised LCC estimates for Annual and Five Year Defense Plan considerations; finally, ILS and Test and Evaluation impacts must be considered. The system aggregation model will help in the preparation of the following documents: Navy Training Plan, Ship Manning Document, Squadron Manning Document, Shore Manning Document, Test and Evaluation Master Plan, and Integrated Logistical Support Plan.

Full scale development ends with DSARC III, which deals with the following issues: the need for producing the system in consideration of threat; acquisition and ownership costs and potential benefits in the context of overall DoD strategy and fiscal guidance; is practical engineering design complete and has adequate consideration been given to production and logistic problems; have all previously identified technical uncertainties been resolved and operational stability been determined by T&E; and finally, is the plan for the remainder of the program feasible.

6.2 THE FULL-SCALE SYSTEM AGGREGATION MODEL

The key to the slide-rule aggregation model system was that by using programmable calculators cost models could be provided to every member of a design team. The models are somewhat simplified, but simplicity is what is required during the crucial early stages of design. However, as the design proceeds it is possible and necessary to conduct finer cost trade-offs based on the more detailed information available. More detailed slide-rule aggregation model systems can be constructed. However, beyond a certain point, the system will become unwieldy. At this stage, a third model system is introduced. This system, the full-scale system aggregation model, is similar in structure to the slide-rule version, but is implemented on a production computer, which allows a wider and more sophisticated range of cost analyses. The full-scale system is the bridge between design and specialized planning. Runs of the full scale model are at first done in parallel with the slide-rule aggregation model system during the validation phase.* During full scale development, outputs of the full-scale system are used as inputs to the specialized planning models used to develop the documents mentioned in Section 6.0.

*The same graded replacement of straw-man data envisioned in the slide-rule model system characterizes the appropriate use of the full scale system. When first used, data demands outrun what is known about the design. As the design is advanced, however, the data base is transformed into a real description of the concrete design.

6.3 MANPOWER EQUATIONS IN THE FULL-SCALE SYSTEM AGGREGATION MODEL

In Chapter 5 we demonstrated how the equations of the slide-rule aggregation model system could be expanded to include a consideration of three level of repair options: local, intermediate and depot repair. Even though the equations presented became somewhat complex, they still were appropriate to a slide-rule system--they could be implemented on a calculator with limited storage and machine capabilities. As the sophistication of the equation structure increases, however, it becomes more and more difficult to program the small machines appropriate to the slide-rule concept. Before this point is reached, it is desirable to be able to shift from a slide-rule to a full-scale production model system. Doing so allows one to take advantage of the greatly enhanced computational capabilities of a production computer to consider finer issues. One example of such an issue is the following. The level of repair equations developed in Chapter 5 were not able to take into account beyond capability of maintenance (BCM) rates. It can be expected that a certain percentage of items coded, say, local repair will not be repairable at the local facility. In such cases the item is either discarded or sent to a higher level maintenance facility to give them a chance to repair it. "Mixed" repair postures are often assigned to items (for example, repair local, send to depot if BCM); these assignments have manpower and training implications for each repair facility. The full-scale system aggregation model is appropriate for dealing with such an issue, for three reasons:

1. The problem has large data input requirements.
2. The issue does not arise until late in the design stage.

3. The solution is computationally complex.

We propose now to develop a set of equations for dealing with the issue of mixed level of repair postures of the elements of a system. The equations will be developed at the subsystem level only: component level equations are explicitly included at this level and the system equations are simply the sum of the subsystem requirements.

To get started, define IS and DS respectively as switches set to 1 if an item that is BCM is to be sent to the intermediate or depot repair facility, otherwise they are set to 0. (An assumption will be that BCM items can only be sent to a higher-level repair facility. That is, an item BCM at the intermediate facility can only be sent to the depot, never to a local facility.) Define LBCM and IBCM as the BCM rates at the local and intermediate repair facilities, respectively. Other variables are defined as in Chapter 5. Finally, we will need the signum function, defined as follows:

$$SGM(x) = \begin{cases} 1 & x > 0 \\ 0 & x \leqslant 0 \end{cases}$$

Local manpower and training requirements do not depend on the mixed level of repair assignment of the components or assemblies (this, incidentally, is the main reason that it is an acceptable approximation to exclude a consideration of mixed postures in the slide-rule model systems):

$$LM_j = (\sum_i D_{ij})MTRR_j + LR_j \sum_i [D_{ij}(LMTRR_{ij} + LR_{ij}LMTTR_i)]$$

$$LT_j = TRR_j + LR_j TTR_j + \sum_i (LR_{ij} TTR_i).$$

There are two ways in which the intermediate maintenance facility can receive the entire assembly: either the assembly is coded intermediate repair or the assembly is coded local repair, send to intermediate facility if BCM. In both cases the intermediate facility removes and replaces the components of the assembly, and repairs those components coded intermediate repair. The intermediate repair facility can also receive components directly as long as the assembly is coded either local or intermediate repair and the component is coded intermediate or local, send to intermediate if BCM. All of these are included in the intermediate maintenance manpower equation:

$$IM_j = (IR_j + LR_j LBCM_j IS_j) \sum_i [D_{ij}(IMTRR_{ij} + IR_{ij} IMTTR_i)]$$
$$+ \sum_i \left[D_{ij}[(LR_j + IR_j)IR_{ij} + LR_j LR_{ij} LBCM_{ij} IS_{ij}]IMTTR_i\right].$$

A training course on the repair of the assembly, TR , is required if the assembly is coded either intermediate repair or local repair, send to intermediate facility if BCM. The same is true for all the components of the assembly:

$$IT_j = SGM(IR_j + IS_j)TR_j + \sum_i [SGM(IR_{ij} + IS_{ij})TR_i].$$

There are quite a few different ways in which an assembly or component can reach the depot maintenance facility. We leave it to the more analytically inclined (and patient) of our readers to verify for themselves that all possibilities are accounted for in the following

equation for depot manpower requirements:

$$DM_j = \left[DR_j + DS_j(LR_j LBCM_j((1-IS_j) + IS_j IBCM_j) + IR_j IBCM_j)\right]$$
$$\left[\sum_i D_{ij}[(DMTRR_{ij} + DR_{ij} DMTTR_i)\right] +$$
$$\sum_i \left[D_{ij}(LR_j + IR_j + DB_j)DB_{ij} + DS_{ij}(LR_j LR_{ij} LBCM_{ij}\right.$$
$$\left.((1-IS_{ij}) + IS_{ij} IBCM_i) + IR_j IR_{ij} IBCM_{ij})]DMTTR_i\right].$$

Finally, a training course on the repair of the assembly is required if the assembly is coded either depot repair, local repair, send to depot if BCM local, or intermediate repair, send to depot if BCM intermediate. The same is true for all the components of the assembly:

$$DT_j = SGM(DR_j + DS_j)TR_j + \sum_i [SGM(DR_{ij} + DS_{ij})TR_i].$$

These extensions, focused on development of estimates for M and Tc, introduced in Chapter 3, are capable of exploiting virtually all the useable information developed by the end of the full scale development phase. By being responsive to changes in the level of repair of any system element, they make it possible to refine estimates of manning, manpower costs and training course contents to the level required for detailed planning. Nonetheless, a variety of more sophisticated computations are possible at this stage. Some of these are discussed in the next section.

6.4 ADDITIONAL TOPICS

The enhanced storage and computational capabilities of a production computer allow the consideration of several issues which can arise during the Full-Scale Development Phase of the WSAP. In this section, we discuss some of these issues. They fall into two major categories: commonality and time-phased manpower costs. The second topic includes the issues of changing force size, personnel attrition rates, recruitment, and ship-shore rotation policies. An algorithm for dealing with time-phased costs will be developed.

Commonality

Many types of costs do not increase as a product of the quantity of an element and its unit cost. Take, for example, the spare stockage (S) and maintenance training (T) requirements generated by a single component of a system. If the component is unique in the system, there is no particular problem in determining S and T. If, however, the component appears N times in the system, the total system level requirements are not given by NS and NT, but rather by formulas similar to the following:

$$S(\text{system}) = I(ND + 1.645\sqrt{ND}),$$

where D is the stockage demand of a single component.

$$T(\text{system}) = T.$$

In other words, the stockage requirement for the component is based on the number of appearances of the component, whereas there is only one

training course for the component regardless of how many times it appears in the system.

Aggregation model systems build up system level costs as the sum of the costs of the system subelements. When such costs cannot be treated individually, but must instead be determined through simultaneous consideration of subelements, this problem is referred to as one of commonality.

Failing to consider commonality will generally result in over-counting. For example, a review of the maintenance "C" school equations developed in Sections 5.2 and 6.2 will show that the equations can double-count the training course requirement of the same component if it appears in two different assemblies.

It is not particularly difficult to resolve most commonality problems. Subelements can be flagged with identifying codes and simple algorithms developed to aggregatage costs correctly. (For example, the signum functions used in Section 6.2 are constructed precisely to avoid double counting of training requirements at the intermediate and depot level maintenance facilities.) However, for slide-rule models there is a trade-off: increased accuracy comes at the price of increased difficulty in use. In most cases, simplicity should prevail: the difference in cost estimates produced by including commonality issues will rarely be sufficient to cause changes in the design path. For this reason, commonality issues were not incorporated into the manpower cost algorithms developed in these guidelines. Commonality should be included in full scale production models, however, where a major design option includes large numbers of common elements. We repeat that

there is no particular difficulty in doing so, provided that designers and cost analysts are aware that the problem exists.

Time-Phased Costing

Up to this point there has been no need to mention time in the manpower cost equations. Suppose a system has a projected life cycle of L years. There are several ways in which this can be incorporated into the manpower cost equations. Annual wage costs can be computed and then multiplied by L, initial training costs are computed and then multiplied by 1 + TOR*L, where TOR is the annual personnel turn-over rate, and so on. Inflation and discount rates can also be incorporated.* This simple time-static costing approach is the one most appropriate to the early phase of design.

Another approach to costing is to compute costs for each year of the life cycle separately: total life cycle cost is the sum of the annual costs. To do this, of course, requires a large and bulky cost model with information requirements equal to those of the time-static versions multiplied by the number of years in the life cycle. Such models are capable of producing impressive cost tables, breaking down costs by each year of the life cycle. In most cases, however, such charts merely consist of numerous repetitions of the same cost (most equal to zero), which are largely ignored by analysts who (correctly) are only interested in the bottom line or, more accurately, in the difference between the current bottom line and that of an alternative design.

*See the discussion of inflation and discounting in Volume II, Chapter 2.

Thus, information requirements and simplicity dictate that time-static models be used during the early design phases. However, time-phased modelling can be appropriate in the later stages of design when planning information becomes more important. Several issues are of importance:

1. Changing force size

   Many systems have a planned phase-in/phase-out schedule. Ignoring this will tend to distort operating and support versus acquisition costs. While the average number of systems deployed during the life cycle can be determined, it may be desired to treat this issue in a more detailed fashion.

2. Personnel attrition rates

   The personnel attrition rates used in most models are derived from a very broad base of Naval personnel. Much more detailed and specific information on each NEC is available in the BCM, but few models are designed to utilize this information.

3. Recruitment

   In Section 3.3 it was mentioned that some proportion of total recruitment costs should be allocated to all new personnel added to a ship's complement. These costs include not only the cost of the personnel themselves, but of those personnel inducted for "agricultural" purposes.* These costs will vary with NEC and skill level.

4. Ship-shore rotation policies

   Personnel wage and training costs are affected by the ship-shore rotation policy of the operators and maintenance personnel. Total training costs, for example, will be greater than are indicated simply by the attrition rate if it is the policy to rotate personnel

*In order to provide N E-5's in the year X, it is necessary to recruit N+A E-1's into the Navy in the year X-X', since over X' years, A personnel will attrite out of the Navy. In the jargon of Naval personnel, these A personnel are said to have been recruited for "agricultural" purposes.

> from ship to shore assignment every N years. In addition, different rotation policies have different wage and training pay-offs. A three year rotation policy, for example, will have higher training costs than a five year policy because personnel will be replaced more often. On the other hand, wage costs will be lower because fewer senior people will be operating and maintaining the system.

We propose now to develop an approach to time-phase mapower costing that treats the issues mentioned above. This approach is an extension of the annual costing approach in current use, and is appropriate to full-scale production models. The approach will be developed through a specific example.

Imagine a system with a requirement for an AC specialist with five years' experience in the Navy. It is further decided that a five year ship-shore rotation policy will be used. The continuation rates of the AC for the first ten years of his career, as given in the BCM, are the following:

Year	Cont. Rate
1	.9840
2	.9150
3	.8770
4	.3775
5	.9500
6	.8380
7	.9030
8	.9530
9	.9210
10	.9250

Table 6.1. AC Continuation Rates*

*Source, Billet Cost Model, Users Manual, November 1976, B-K Dynamics, Inc., TR-3-227, p. B-2.

The system will be phased-in and out over a ten year period, as shown in Table 6.2.

Year	# Platforms
4	0
5	25
6	50
7	75
8	100
9	100
10	100
11	100
12	100
13	100
14	50

Table 6.2. Phase-In/Phase-Out Schedule

Note that the first year of deployment corresponds to the fifth year of service for the initial AC's.

In year 5, the first year of deployment, 25 AC's are required. We can use the continuation rates for the AC to work backward to determine how many AC's must be recruited in year 1 to supply the 25 AC's in year five, and to work forward to determine how many of the AC's will remain in years 6-9, after which they will be rotated to shore assignment. The results are as presented in Table 6.3:

Year	1	2	3	4	5	6	7	8	9
# AC	84	83	76	66	25	24	20	18	17

Table 6.3. Initial AC Recruitments by Year

As Table 6.3 shows, in order to supply 25 AC's in year 5, it will be necessary to recruit 84 AC's in year 1. By year 9, only 17 will remain.

Year 6, the second year of system deployment, has a requirement for 50 AC's. According to Table 6.3, there are only 24 AC's left, so an additional 26 must be provided. Using the continuation rates again, we can add another row to Table 6.3:

Year	1	2	3	4	5	6	7	8	9	10
#AC2	-	87	86	79	69	26	25	21	19	18
#AC1	84	83	76	66	25	24	20	18	17	-

Table 6.4. Initial and Second-Year AC Requirements

Year 7, the third year of system deployment, has a requirement of 75 AC's. There are 20 initial AC's, and 25 second year AC's, so an additional 30 men must be "cultivated" by that time. By now the pattern for developing the chart of personnel requirements presented in Table 6.5 should be clear.

The numbers underlined in Table 6.5 represent the number of AC's who must receive initial system training ("C" school) in each year of the system life cycle.

This approach to time-phased manpower costing breaks down manpower costs more explicitly than is usually done and reveals manpower costs

AC9									94	92	85	74	28	27
AC8								97	96	88	77	29	28	23
AC7							50	50	45	40	13	14	12	11
AC6						117	116	106	93	35	33	28	25	24
AC5					34	33	30	26	10	10	8	7	7	
AC4				107	106	97	85	32	30	25	23	22		
AC3			101	99	91	79	30	29	24	22	21			
AC2		87	86	79	69	26	25	21	19	18				
AC1	84	83	76	66	25	24	20	18	17					
req.	0	0	0	0	25	50	75	100	100	100	100	100	100	50
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14

Table 6.5 System-Life Cycle AC Manpower Requirements

not usually considered. For example, the breakdown of year 8 indicates that the 100 man requirement for AC personnel is met by 32 fifth-year men, 29 sixth-year men, 21 seventh-year men, and 18 eighth-year men, each of whom have different annual billet costs. In addition, during that year it will be necessary to recruit 97 new people into the Navy, and find work for 50 second-year men, 106 third-year men, and 26 fourth-year men, all of whom are in the Navy solely to provide the necessary personnel to man the system in the outyears. The proper allocation of this cost to the system was discussed in Sections 2.2 and 3.4, above.

APPENDIX

Billet Cost Differences

BILLET COST DIFFERENCES

The least cost algorithms developed in Chapter 3 depend on the assumption that training - specifically "C" school - has the effect of raising billet cost for a given individual. If this assumption were untrue, that is, if Bn=Bg, then the opportunity cost structure of those algorithms collapses to the special case currently in use in the Navy. Establishing the likelihood of such a difference (Bn>Bg) is therefore important to the argument developed in Chapter 3. Doing so is also made important by the feeling, indeed the empirical evidence, that grade increases appear to be a function of length of service (LOS) to the exclusion of other variables.

In this appendix we offer four arguments for the assumption that Bn>Bg. First we argue that training has an impact on the future wage or career path of the trainee, raising the appropriately discounted present value of that cost stream measured at the decision point in the design process. Second, we argue that the appropriate value of Bg is a value foregone, rather than an offsetting technical cost. Third, we argue that because of the general nature of much of the training recieved (i.e. its saleability in competitive labor markets) properly measured billet costs will be forced to rise

despite personnel policies traditionally geared to making grade a function of LOS. Finally we argue that currently discernable policy shifts will lead to the breakdown of observable correlation between pay rates and LOS as time passes. These arguments are presented in detail in the following paragraphs.

Human Capital

Assuming, for the moment, that LOS has a "pure" effect on all military wages, raising them by the annual rate w, other factors will tend to increase or decrease this value over time. Those other factors include a variety of things from the luck of assignments to the attrition rate of the LOS cohort. One consistent and predictable element, however, is training: the potential value in use the individual represents to the Navy. Whether the increment of value is large or small, we choose not to address. Instead, we argue simply that it is positive and, other things equal, more training leads to high wages. The increment in wage cost can be portrayed mathematically as the discounted present value of the difference in future wages (and other income paid by the Navy) resulting from training. Let the current actual wage be Bg and the private rate of increase in income due to training be r. Then the present value (PV) of future increases in wage cost is given by:

$$PV = \sum_{t=1}^{n}\left[Bg[(1 + w + r)^{t} - (1 + w)^{t}]/(1 + d)^{t}\right]$$

Notice that, even if r is very small, it interacts with w so that the net change given by PV can be substantial. This works both ways, of course. If other factors cause the value of w to be small, then the impact of r is correspondingly diminished.

Value Foregone

The human capital argument might be called "weak" in the sense that we can develop no concrete expectations about the size of the difference in expected present values - only the direction of difference. Consideration of value foregone is, correspondingly, a "strong" argument. We have used the value Bg as a measure of value foregone. In the text of Chapter 3 we stated that, with no other information to go on we would accept the cost to the Navy of the lowest skill billet as the value of such work to the Navy. Here we replace that assumption with an analysis of the value of what we called "non-prime" labor.

To understand the real cost to the Navy of underutilizing skilled labor in the manner described, we use the example of paint chipping introduced in the text. Imagine now that paint chipping is an important Navy mission and attention is turned to the problem of producing requisite quantities of chipped paint in the most efficient manner.

The hypothetical current situation is that 200 men spend an average of one hour during each of 250 work days producing the required amount of chipped paint on a single ship. This comes to a

total of 50,000 manhours or just over 24 man years of labor. Using the convention that the lowest skill billet cost estimates the value of this labor correctly, we would cost the 24 man years at about $10,000 each for a total cost (value) of $240,000 for the ship. Now imagine that the efficient alternative requires a team of two skilled technicians (salaries equal to $20,000 per year) and capital stock of $100,000. Imagine further that this combination of resources requires one month to service the ship and that the capital is fully utilized during the remainder of each year. Now if the capital is amortized over a period of ten years, the total annual cost of producing the right amount of chipped paint is $4,167 of which $3,333 is labor and the remainder capital depreciation expense. To complete the argument, we now compare the efficient method of obtaining chipped paint to the method which supposedly yields a value of $10,000 per man year. The economic value of that amount of chipped paint is, in fact, the cost of the most efficient method of producing it - namely $4,167. Therefore, the value of those 50,000 manhours is $4,167 which works out to an hourly value of 8.3 cents and a manyear value of $173.35.

While this illustration is, as it was meant to be, somewhat startling, it is not necessarily far from reality. A careful estimate of the value of men in "non-prime" uses would actually be based on a weighted sum of several different activities, the amount of time devoted to each, and a separate analysis of the sort presented to determine the hourly value of each. While such an analysis would not show that virtually the whole value of a man is

lost when he is working at something other than what he was trained to do, it would, more than likely, show that very substantial value is lost.

Competitive Labor Markets

The provision of highly specialized training is normally viewed as a low risk investment in human capital. This is because "specialized" implies a higher value of the skill to the provider than to any other buyer of labor. That is, the training is said to be "specific" to the employer who provides it. Similar devices that specify a worker to an employer include such things as partially vested pension plans and employee discounts on merchandise produced or sold by his employer. There is a confusion of technical terms here best illustrated by the statement that while "C" school, for example, is highly specialized in one sense, it turns out not to be specific to the Navy insofar as labor markets are concerned.

There are at least twenty firms (and may be as many as fifty) whose major line of business is the sale of specialized contract labor to the U.S.Navy. Average man year costs run in the neighborhood of $50,000 a year and sometimes higher. Direct compensation to the workers can be as high as $35,000 a year. Generally, this labor force is recruited from Naval technicians with 10-20 years LOS. Whether acknowledged or not the Navy must compete in this labor market to retain its technicians. The competition takes a variety of forms, all delivering compensation to the technicians. These forms

include, over the stipulated wage rate, reenlistment bonuses, extended shore duty assignments, special schools and more informal perquisites in specific cases.*

Thus, while it may be demonstrably true that a Bosun's Mate with 18 LOS has the same pay and allowances as an electronics technician, the current pay and allowance level is a substantial underestimate of the cost of the latter. In effect the technician remains in the Navy because of a pronounced preference for Navy life. He occupies a position on the lower portion of the labor supply function. Large numbers of his fellow cohort members, who occupied positions at higher levels of the supply function have left the Navy for higher compensation elsewhere. In effect, then, the cost of the technician is not only his current pay and allowances, but the costs associated with lower survival rates for his cohort. Empirically, one would look for relatively low cumulative retention rates for skilled rates, other things equal.

Policy Shifts

The last argument in favor of the assertion that Bn-Bg is significant relies on recent policy initiatives and the reasons for their occurance. During September, 1978 a bill was signed into law making fundamental alterations in the rules and philosophy governing

*While there are several buyers of this labor force in the Navy, the most important is NAVSEA 04 (Fleet Support). That organization buys labor through the MOTU (Mobile Technical Unit) program as well as the CETA (Civilian Electronics Technicians Afloat) program.

grade increases for civil servants in the "super" grades: GS-16 through 18. The essence of the change appears to be to replace automatic increases related to LOS with merit increases. If it is reasonable to project future changes on the basis of this evidence, then we may find that the close correlation between LOS and pay currently observable in the military will begin to break down at some time in the future. When and as the correlation between those two measures is weakened, it will be of importance to the Navy to have computational structures that accomodate opportunity costs based on the difference between Bn and Bg.

AG-PR-A100-2

VOLUME II

METHODOLOGICAL REQUIREMENTS FOR MANPOWER COST ANALYSIS OF HARDWARE SYSTEMS

by

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October 1978

Contract No. N00014-77-C-0809
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Submitted to:

Scientific Officer
Office of the Chief of Naval Operations
Department of the Navy
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EXECUTIVE SUMMARY

This volume presents a brief treatment of some fundamental concepts in hardware/manpower cost analysis. It is intended to provide the theoretical underpinnings of the guidelines presented in Volume I of this report. While the latter are, in many instances quite detailed, they could not possibly be considered exhaustive in covering all cost analytic problems. It is hoped that an understanding of the economic issues dealt with here will enable analysts to fill the gap.

The term cost basis is used to describe the set of fundamental rules and assumptions implied by the structure of a cost model. Cost basis includes the answer to the question: Cost to whom? It also covers the treatment of overhead costs and the extent of cost coverage. While we recognize that several special accounting and budgetary rules reduce an acquisition's effective cost to the Navy below its real economic cost, we choose the latter as a recommended guide. The reasons for this are complex, but lean most heavily on the need to represent relative factor prices as accurately as possible. The use of overhead or "burden" rates is rejected in favor of explicit analysis of support costs wherever feasible. The complexity, indeed, the near impossibility, of tailoring cost coverage to a specific trade-off area leads us to recommend that doing so be avoided - again, to avoid distortion of relative factor prices.

The economics of capital labor substitution are discussed and the concept of an isoquant introduced to portray the mechanics of hardware/manpower trade-offs. Discontinuous isoquants are introduced as a schematic representation of the economic problem involved in choosing among technologies or among design approaches. The inferences drawn for cost analysis are that cost methods must be capable of portraying alternative design approaches (as opposed to the continuous isoquant model) and they must also be capable of estimating the relative factor prices of hardware and labor accurately.

A discussion of parametric methods concludes that they are most useful in the estimation of acquisition costs in the earliest stages of the weapon system acquisition process. For operating and support costs (and therefore life cycle costs) a different approach called process modeling is more appropriate. These findings are based on three inherent weaknesses of parametric methods: the critical

assumptions error, limited dynamic range and inappropriate policy variables. The critical assumptions error arises because parametric methods use proxies for the variables of interest. Since the relationships between the proxies and the real variables are constantly shifting, the parameters rarely express true relationships. Parametric relationships also work best over a dynamic range limited to the average experience reflected by underlying data. Therefore, technological departures tend to be poorly estimated since they represent "outliers" to the data set. A policy variable measures something under the control of the analyst. For example, the reliability of a component is a policy variable to a component designer, whereas the reliability of the system is not. Parametric relationships rarely use policy variables for any of the actors in the acquisition process and their usefulness is therefore limited to cost estimation rather than cost analysis.

PREFACE

Volume I of this study is intended to provide concrete guidance to the program manager and cost analyst in developing a methodology for comparison of labor and hardware costs throughout the Weapon System Acquisition Process (WSAP). But specific guidance can only be given at the risk of inappropriate application. We do not believe that the development of cost analysis tools lends itself to the "cookbook" approach, and Volume I reflects this bias in the way its results are written.

This volume is intended to provide the theoretical underpinning for Volume I. Appropriate application of the guidance of Volume I, in the case of unforseen cost problems, should require that the analyst understand the theoretical background. If he does, it should also be the case that virtually any cost problem will prove tractable.

We are indebted to a very large group of people who have contributed to this effort. Commentary on an earlier draft from Mr. John Bartholomew of the Naval Weapons Engineering Support Activity and from Commander Gentz of the Office of the Chief of Naval Operations (OP-96D) were particularly helpful. Without question, however, the most significant contributions were made by Mr. Paul Hogan, originally the Project Officer, and Lt. Commander Lee Mairs, both of the Bureau of Naval Personnel (PERS-2122). Notwithstanding these debts, the authors take full responsibility for any remaining errors.

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1.0 INTRODUCTION

While Volume I of this study sets down relatively concrete guidance for the development of cost methods, this Volume is aimed at establishing the theoretical rationale for those guidelines. In particular, some standard results in economic theory are discussed and used to establish generally applicable rules of cost analysis as it pertains to the manpower content of hardware life cycle cost.

In the development of this study, the first step was to understand how the Navy currently undertakes life cycle cost analysis in a variety of applications. The detailed results of that review, published as Volume III, focused attention on several problems. The discussion of this Volume reflects those findings in that the subject matter is responsive to the problems.

The first difficulty was that most of the models were overly complex. While there is nothing wrong with complexity, *per se*, it makes the use of a cost model more difficult. If that difficulty is unrewarded by substantial increases in the accuracy or other value of the model's output, then complexity represents a problem. Probably the most important result of complexity is to diminish the extent of use of a model. By requiring large and detailed input data sets, the models are disqualified as aides in the early portions of the design process when the data are unavailable.

Another major difficulty was inadequate coverage of manpower costs. These deficiencies included operator and officer personnel costs, security clearance costs and indirect or support labor costs. While each of these costs are covered in some models, they are excluded from others, and no model included all costs.

Cost coverage deficiencies are compounded by inappropriate formulations. It is in this area that the present volume fills an important gap in cost analytic methods. As an example, wage costs for maintenance are generally computed by multiplying the number of expected hours of work by a wage rate. The concept of opportunity cost, as developed in Volume I, is absent from such formulations.

It should be understood that while concern for manpower cost is not new, the notion of tying manpower cost analysis to hardware life cycle cost analysis *is* new to the Navy. Thus, the remarks above and subsequent critical commentary on existing methods should not be taken as damning their creators. In fact, at the same time that we noticed deficiencies with regard to manpower costing, we also saw that most of the models did an adequate job in the areas they were intended to cover. One central concern is to *extend* those methods, so that they can address the full range of life cycle cost consequences of new system acquisitions.

Section 2 is a discussion of the basic concepts of labor cost analysis. It is divided into two parts. The first is concerned with cost basis and the second with coverage. Section 3 discusses life cycle cost models as trade-off tools, focusing particularly on capital-labor substitution. Section 4 is devoted to parametric cost estimating methods and their utility in the Weapon System Acquisition Process.

2.0 LABOR COST CONCEPTS

Cost can be calculated in a variety of ways. One way to distinguish among them is to ask the question - cost to whom? The answer might be to the procuring program office, the Department of the Navy, the Department of Defense, or the U.S. Treasury. This list is not fanciful: cost models are in existence and being used which are predicated on each of these concepts. They are being used to make the same or similar decisions, and sometimes their answers are compared to each other for the purpose of decision-making. This is a sufficiently important problem that an illustration in concrete terms is warranted.

Imagine that a new weapon system is being developed for which there are some labor cost implications. Typically, the procuring agency will decide between competitors or between design options on the basis of cost estimates which include no labor costs whatever: they will be concerned almost exclusively with the relative procurement costs of different system alternatives. The Department of the Navy, however, must pay certain manpower costs and makes its decisions on the basis of models which reflect these costs. Two costs which will be ignored are retirement benefits, and the cost associated with the income tax advantage created by the allowance portion of military pay. The Department of Defense, which must bear some of the retirement costs for military personnel will calculate an even larger cost for manpower. Finally, the Treasury or the Congress may well take account of the income transfer payments implied by non-taxable allowances. Since most programs are subject to approval at each of these levels of government, it is no surprise that the competition for funds becomes

stiffer as the review cycle penetrates each successive level--where the concern is for a wider definition of cost.

The problem illustrated above is one of several associated with what is called cost basis. Other problem areas include the distinction between marginal and average cost concepts and the treatment of overhead costs, opportunity cost problems associated with the notion of economic rather than budget costs and the way time influences costs.

Another set of issues can be referred to as coverage problems. The coverage of any cost model is an extremely important indicator of its accuracy. Elegant formulations and extensive statistical verification, while important, tend to make insignificant contributions to accuracy when compared with simple matters of coverage. For example, most hardware cost models which include labor costs are restricted to direct wage costs and training. The wage rate used in these formulations is generally the subject of extensive statistical analysis. However, for some systems, the costs of obtaining security clearances (usually not covered) can far outweigh the direct labor costs of the cleared people.

The next two subsections discuss problems concerning cost basis and cost coverage in greater detail.

2.1 Cost Basis

Accounting structures and cost basis are, ideally, developed to suit the particular requirements of a cost analysis. Those requirements may be to develop justification for design choices, identify least-cost

maintenance policies, compare alternative system configurations, perform source selection between competing contractors, develop performance specifications for conceptual designs or structure out-year budget submissions. Each of these objectives *could* lead to a distinct chart of accounts to be incorporated in a model. They would also lead to different functional relationships, using different constellations of input values or cost drivers. Some writers believe that all such models should ultimately be tied to a single budget accounting structure.* While one would not argue with the desirability of such an objective, its importance is arguable. A more pressing need is the development of consistent guidelines for cost basis, the topic of this section.

The issues involved in cost basis are complex. Moreover, many of the choices which should be made to develop consistent guidelines for all models amount to essentially arbitrary policy choices: there is no particular economic rationale which provides an absolute guide for choice. The most important element of the cost basis problem--Cost to whom?--was discussed briefly in the introduction. The following paragraphs discuss several other related elements.

Marginal versus Average Cost and the Treatment of Overhead

A significant issue in the use of cost analysis for procurement is the distinction between marginal and average cost, since the former

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* See, for example, K. E. Marks, *et al*, *Life Cycle Cost Estimation for USAF Aircraft Systems: An Appraisal of Cost Element Structures and Estimating Methodologies*, The Rand Corporation, R-2287-AF (forthcoming), Santa Monica.

reoresents the actual imnact on the Navy of a decision to procure a new svstem. Brieflv, average cost is eoual to total cost divided by the number of units. Marginal cost is the change in total cost resulting from the introduction of one extra unit. In more familiar terms, the difference usuallv arises in the treatment of what might be called "overhead" costs. Headouarters functions, the training establishment, shipvards and many other elements of the Navy can be treated as overhead-- or mav not. There is no general agreement on the chart of accounts which would distinguish between direct and overhead categories of cost.

There are at least three categories which suggest themselves as useful when considering the distinction between average and marginal manpower costs. First, there are some costs which must be borne, and whose size would not change appreciably under various conditions if we are to have a Navy at all. At the other end of the spectrum are those costs created specifically by the induction of one additional man to the service. In between are a group of variable costs which only vary in steps and are related to the size of the Navy. For example, an additional cook might be required on a land base for every 200 sailors added to the facility, while an additional baker would be required for every 500. Both the first and the last are overhead costs. The distinction between them is simply that the addition of a single man to the Navy would in one case be capable of calling forth an increment in overhead costs, while in the other the overhead cost is determined independently.

Opportunity Costs

A philosophical issue arises to further complicate matters. The Navy (like the Air Force) is primarily an operator of weapon systems and not a fielder of an armed force (like the Army). That is, men play a subsidiary role to the weapon systems they serve. As a consequence, manpower budgets tend to be determined on the basis of weapon system crew requirements and not for the sake of having men in the Navy. Yet, the determination that so many dollars will be allocated to Naval manpower procurement is usually a process which is independent of the decision to procure any element of hardware smaller than a platform. In considering the cost of a ship's equipment, then, should the cost of a man be ascribed to that equipment as a marginal cost? The arguments for not doing so are compelling. In effect, we want to account for all costs which are relevant to the decision to purchase that equipment--that is, the marginal costs which are associated with it. Yet the manpower budget has already been determined or will be determined without regard to the equipment in question. As a consequence manpower costs should *not* be included in the decision. If this line were taken, decision making would be predicated on the planning function of matching pre-determined resource levels rather than the relative price of different options.

The Role of Time

Another area of considerable difficulty concerns inter-temporal cost comparisons. Two subjects are of concern: inflation and discounting. A change in relative prices over time is the only significant aspect of inflation:

when some factor prices change more rapidly than others, factor proportions should be changed to minimize the cost of a fixed output level. General price increases are unimportant in life cycle cost analysis because they imply no changes in factor proportions.* Since the deliberations of the Gates Commission, the introduction of the All Volunteer Force (AVF) and the introduction of the notion of parity between civilian and military pay, the armed forces have been faced with a rapid change in the relative price of manpower compared to hardware. Indeed, one might imagine that this study and much related work has been undertaken as a direct consequence of that change in relative factor prices.

The use of discounting is necessary to interpret the value of a cost stream at a point in time (i.e., convert a cost flow to a cost stock). Expenditures at future times are less costly than current expenditures and their dollar amount is decreased accordingly for comparison to present amounts. To understand why future expenditures are "less costly," consider the fact that one could invest $1 today against future costs and, at a rate of return of 10%, be able to defray $1.10 of costs a year from now, or $1.21 two years from now. Thus, a cost stream which, undiscounted, appears to be worth $2.31 over two years is really only worth $2.00: an overstatement of 15.5%. The degree of overstatement rises with 1) the appropriate value of the discount rate, and

*There are, in practice, some exceptions. Until the 1% "kicker," retirement pay costs dropped as the general price level rose - now the reverse is true. In general, any assets whose yield is fixed in money terms become less costly (valuable) during general price rise. The practice of "indexing" is intended to overcome this effect and make general price rises neutral for the holders of such assets.

more importantly,, 2) the length of the cost stream.*

The importance of discounting in the consideration of manpower cost arises from the fact that, unlike acquisition costs, all labor costs are incurred over long periods in the future. In other words, a straight comparison of labor costs and hardware costs, without discounting, tends to overstate the cost of labor. In the kinds of cost models generally used, this is not a problem in comparing hardware and manpower components of operating and support costs, since these are both future costs. It is, however, a problem in considering the tradeoff between operating and support costs (to be borne over periods from ten to twenty years into the future) and acquisition costs.

For a variety of reasons, both policy and a result of the state-of-the-art of cost modeling, neither price adjustments nor discounting are widely used in military cost analysis. This is not to say that mechanisms are not available in the model structures, since most have them. But in practice, these features of the cost models are usually suppressed. With regard to inflation, the problem is simply that price level changes are extraordinarily difficult to predict over even short periods, no less a period like ten to twenty years. To be even more precise and distinguish between labor and capital prices, as well as other pertinent cate-

*This discussion obscures the distinction between discount rates and interest rates or rates of return as a heuristic device. While the distinction is important in some areas, it is of little interest here.

gories, is correspondingly more difficult.* Since the reliability of such estimates is so suspect, cost analysts are generally reluctant to use them. Discounting, too, is generally shunned as a policy by the military departments. The general attitude seems to have been that life cycle cost models appear to underestimate operating and support costs rather badly anyway, and discounting would simply accentuate this problem.

2.2 Cost Coverage

In most cost models, manpower cost coverage is limited to two major categories. These are training costs and compensation costs associated with direct labor input to maintenance tasks. The latter is generally predicated on the number of corrective and preventative maintenance manhours generated by the activity rate, failure rate, and mean time to repair (MTTR) of a given hardware system. Hourly wage rates are applied to the resulting number of manhours (the wage is usually based on regular military compensation, RMC) and the product is considered an estimate of labor cost. This kind of coverage significantly understates the actual manpower costs generated by a new hardware system.

The three major classes of manpower costs are compensation, training, and other costs. Compensation, a minor element in the cost estimates

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* During the last three years, public awareness of inflation has finally been raised to the level where the use of price inflators in cost models has become more prevalent. Their introduction to cost models usually is commanded by people concerned with budget costs, however, rather than achieving efficient factor proportions. One exception to this is the U.S. Army Electronics Command which publishes price indices for R&D, production and labor costs, separately. Two other exceptions, happily, are the Navy's Equipment and Major System Cost Guides.

produced by most cost models, is probably the largest cost in reality. These three cost classes, furthermore, must be estimated for both operators and maintenance personnel, although the former are only occasionally found, and only in system level cost models. Finally, manpower costs associated with the officer corps are rarely treated in life cycle cost models. The three major cost classes for manpower are discussed below.

Compensation

Regular Military Compensation (RMC) includes basic pay, quarters, and allowances. Since the latter two elements are non-taxable, a fourth element is included by implication: the tax advantage associated with non-pay compensation. This definition of a military wage rate excludes (considering all services jointly) more than thirty percent of actual compensation. The residual elements are dominated by retirement and medical benefits.* Nevertheless, wage rates used in most cost models are an attenuated form of RMC which ignore the tax advantage (roughly three percent of total compensation and a correspondingly larger part of RMC).

If the adjustments implied above were introduced to the kind of wage formulation used in most models, the result would still be quite far from reflecting true compensation manpower costs. The most significant omission

* See Canby, S. and R. Butler, "The Military Manpower Question," in *Arms, Men and Military Budgets*, pp. 185-203, Crane, Russak, New York, 1976.

is that of overhead costs. In Section 2.1, we discussed some of the problems associated with overhead. Another version of overhead costs has to do with the linkage between manpower requirements in direct uses and those in indirect or supporting roles. For example, the addition of a sailor to a ship, directly employed in maintenance of equipment, calls forth an increment in required manpower for managerial, administrative and support roles. But to burden the direct labor cost with some overhead percentage would distort the outcome of a tradeoff analysis by destroying the marginality of the wage calculation. In other words, to save a half a manyear of direct labor would probably have no influence on the real support overhead burden. Instead, it would raise the proportionate burden applicable to the remaining manpower costs.

There are planning methodologies in use in other services which perform detailed manpower cost estimates on the basis of known linkages between direct and indirect labor. These models are simulation programs and are extremely difficult to use because of their size and data requirements.* The point to be made, however, is that such estimation is at least conceptually possible. Whether adequate linkages could be developed to make their use feasible in the cost analysis of equipments is a question worthy of attention.

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* The Air Force uses a simulation model called the Logistics Composite Model or LCOM. For a brief description, see Fisher, R. R., *et al*, *The Logistics Composite Model: An Overall View*, RM-5544-PR, The Rand Corporation, May 1968.

In the absence of fixed relationships between direct and indirect labor types, marginal costs of labor compensation are best approached through the use of an estimating device such as the Billet Cost Model (BCM). The second half of the compensation cost problem is the computation of the number of (direct) men required for a system.

As noticed above, current methods, at best, rely on the incidence of failures or preventative maintenance actions, and the expected duration of these actions, to build up a quantity figure. This method is deficient in at least two ways, one easy to remedy, the other difficult. The first problem is that mean time to repair or mean preventative maintenance time do not describe the actual amount of work time involved in a repair. They exclude a variety of things such as make-ready and put-away time, maintenance documentation requirements, time costs of supply transactions necessary to obtain repair parts and a variety of other elements.* These costs are reflected in the Air Force term mean maintenance hours per flying hour, but are excluded from the technical definition of MTTR. A correction based on a fixed relationship to MTTR would be relatively easy to introduce.

The second problem with current methods for estimating manpower quantity requirements is related to the staffing requirements against a

*The definition of MTTR varies considerably, depending on the service, type of system and concerns of program management. Rarely, however, does MTTR - a concept originally developed to measure how quickly a system could be returned to service - intentionally measure the work time required by maintenance of a system.

particular billet. For both maintenance and operator personnel, it will be necessary to purchase more labor time than is actually utilized by the system. A minor source of this difference is created by leave, sick time, and similar deletions from delivered work hours. Some of these are covered in billet cost estimates, although the documentation is sketchy and this coverage may be incomplete.

Another form of compensation cost never accounted for arises from the under-utilization of skills. The costs of *providing* the skills may be computed correctly under the heading of training. But once an individual is trained, his level of compensation usually rises, partly as a function of the skill level he has achieved.* If, part of the time, that person works at tasks other than the ones he was trained to perform, then his skills are being under-utilized. As an example, imagine a radar repairman who spends half his time chipping paint.** If the billet cost of a repairman (the primary skill) is $15,000 and that of a paint chipper (the secondary skill) is $10,000, then the Navy is paying $2,500 a year too much to have paint chipped.

The $2,500 cost is the potential gain available to achieving better matches between skills and labor requirement--a personnel planning function,

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* This assertion is arguable, although not strictly necessary to the thesis. Compensation costs may be solely a function of seniority, but total billet costs are not. If this were true, then the argument made here concerning the cost associated with underutilized training would simply be more appropriately made in the training section below. Nor is it arguable that the *value* of labor, if there were an output value function for military production, is related to the skill level of the worker.

** Chipping paint is meant as a symbolic term to represent a variety of tasks that are appropriate to unskilled labor.

as well as a ship design problem. If this cost were properly reflected in a cost model used for equipment or subsystem acquisition, it would support capital/labor tradeoffs leading to simpler training requirements and a reduction in the difference between primary and secondary billet costs. [That is, tradeoffs at that level would not raise the utilization rate for the primary skill, but lower the relative cost of the primary and secondary skill billets. In fact, at the subsystem or equipment design level, the impact on utilization would usually be to lower the proportion of time the primary skill were used at the same time it reduced the cost of the skill.]

An interesting subset of the utilization problem occurs with operator personnel. Very little attention is given to operational profiles for new systems specification. Instead, gross activity rates are the object of analytic attentions, so far as cost questions are concerned. The reason for this is that most of the cost models available are driven by gross activity rates. To see the importance of profile, imagine two systems, both having an activity rate of eight hours a day on average. One actually operates eight hours every day while the other operates for twenty-four hours every third day. For a ship system, three times the number of operators must be available to the second system as to the first. Nonetheless, the direct labor hours charged against the system will be the same in both cases. The excess personnel used in the second case will be occupied chipping paint. To see the costs involved, imagine billet costs (or values) of $15,000 and $10,000:

	Eight-hour System	Twenty-four hour System
Billet cost of direct labor	$15K	$15K
Billet costs of under-utilized labor	0	30
Billet value of under-utilized labor	0	(-)20
Cost of operational profile	0	$10K

The cost of $10,000 would be repeated for every ship on which the system were installed and every year of its useful life. Assuming the relevant values were 200 ships and 10 years, the cost is $20 million.

Training

Some form of training cost is usually computed in equipment cost models. The normal approach is to determine the number of billets to be trained and the course cost exogenously, and then base life cycle costs on the system life cycle and the turnover rate. Some models go a step further and distinguish between operator training and maintenance technician training. Few build up course costs or number of billets internally, however. As a result, while coverage may be adequate, the value of the models as tradeoff tools is lessened.

The most commonly encountered error in training cost computations which *do* build up an estimate of the number of billets is to confuse training and compensation billets. As noticed in the discussion above, direct labor years are related to, but far fewer than the number of billets which must be trained. To illustrate, imagine a system which includes ten nomenclatured equipments. Maintenance technicians must be trained

for each of the equipments even though only a few hours of direct maintenance labor are required each year for the entire system. The confusion between training billets and compensation billets would cause a model to "buy" one training course for the system as a whole. That one course may or may not include enough training hours to cover all ten equipments--depending on the particular model. In fact, however, it is necessary to isolate the need for ten different courses, to cross-train or provide backup training of at least one additional man for each of the equipments and to account for a variety of fixed costs associated with each of the ten courses (primarily TDY and transportation costs). The differences are likely to be quite large.

An interesting omission from most models is the cost of personnel security clearances. While only occasionally applicable, these costs can be sufficiently important, when they are pertinent, to have a profound influence on system design and configuration. As an example, the Navy Command and Control System (NCCS), still in the system architecture stage, includes communications security equipment and handles various types of exotic intelligence data. Each node in that system (there could be as many as four or five hundred) must be staffed by individuals with clearances backed by extended background investigations (EBI's) rather than the normal checks. It is not unreasonable to assume that the cost of these EBI's could run as high as $50,000 each, with a five-year update requirement for careerists. Because the computation of the number of security billets is analogous to that for training billets rather than direct labor billets, the addition of clearance costs increased the manpower cost estimate for

that system by more than an order of magnitude.

A second major category of uncovered costs are those of officers. Very few models include the costs of officer manpower associated with a specific system. One task is to assume all officers to be a form of overhead who perform managerial and decision making functions for the Navy as a whole, rather than for specific weapon systems. While that may be a reasonable statement of a philosophical objective, it hardly jibes with reality. A similar group of costs are those associated with civil servants and direct hire personnel related to specific weapon systems. Again, the allocation is generally to overhead and again, this allocation is erroneous, though lacking the philosophical rationale noted for the treatment of officers. The discussion of compensation costs, above, was concerned with overhead labor among other things. As most models are currently formulated, this complex of manpower costs performing administrative, managerial and support functions related to the number of direct labor billets employed are also uncovered.

If the argument made earlier about costs associated with under-utilized skills is accepted, then there are hidden costs of rotation. Most of the weapon systems with which this study is concerned will be deployed and operated only at sea: very few will have more than a handful of installations ashore. As a consequence, shore rotation billets will tend to underutilize the skills developed for the deployed system. Moreover, the skill itself tends to atrophy when not in use. As a result, there are undoubtedly also substantial uncounted costs of informal on-the-job training which arise when an individual returns to sea duty after a period ashore.

Though not a cost directly associated with rotation policies, retraining costs have the same effect. Whether used as a retention device or to overcome the lack of appropriate shore billets, many careerists are trained in several specialties by the end of their careers. Unless such retraining is managed in a very careful fashion, this practice implies a large cost of unused skills.

3.0 COST MODELS AS TRADEOFF TOOLS

In the early stages of the WSAP, when the final form of a new system has not yet been determined, that determination represents an opportunity to achieve low life cycle cost. The opportunity can only be seized, of course, if options or alternatives can be understood as different cost-generating outcomes. The alternatives must be capable of being costed with enough sensitivity to reveal what it is about them that drives cost differences. Our concern here is labor cost and specifically, how labor and capital can be substituted for each other over the life of a weapon system. A related concern is substitution between types of labor such as military and civil service.

Cost elements are incorporated into models in a variety of ways. These can extend from the use of throughputs to the use of analytical or process formulations and finally to cost estimating relationships. A throughput is a number which is read into a model at one end and repeated at the other. In other words, it is not transformed at all by being processed through the computer program and, in fact, is not part of the mathematical model structure.

A process formulation is a mathematical statement of the costs associated with a particular process. For example, a common expression for computation of specific training costs is:

$$C = nBc\ (1 + tL)$$

where n is the number of installations at which the system will be deployed, B is the number of billets to be trained at each installation, c is the

cost per man for the training course, t is the personnel turnover rate, and L is the number of years over which the equipment is expected to operate. By removing the term c, the remainder of the expression provides a quantity, while c is the price associated with training. The quantity computation is based on a process: the way in which military personnel are cycled through a particular billet.

A cost estimating relationship provides an alternative form of parametric cost estimation which is generally sensitive only to a few variables. A training cost equation might, for example, look like:

$$C = a + bW$$

where W is the weight of the system and a and b are parameters. Cost estimating relationships (CER's) are most useful in acquisition cost estimating, and less so in estimating operating and support costs. The principal reason for this is that estimation of the coefficients requires a large data base and no such data base is available for operating and support costs. A more subtle problem arises in any application of CER's. Weight or volume or any one of a number of independent variables typically used in CER's are "proxies" for something else that the analyst is trying to measure. Usually they are bad proxies for the simple reason that the real variables are constantly changing their relationships to the proxies.

The manner in which cost elements are incorporated in a model is a determining factor in the model's utility as a tradeoff tool. The objectives of tradeoffs are discussed in the next two subsections. The discussion is theoretical, concentrating on the most fundamental aspects of capital/labor substitution. In the last part of this section we draw implications

for the structure of cost models from the joint consideration of the abstract argument and an understanding of the environment in which these models must be applied.

3.1 Labor Cost Responses to Capital Change

As discussed above, the real proof of the pudding for a tradeoff cost model lies in the sensitivity of computed cost to changes in the model's independent variables. In this case, we are interested in the cost sensitivity of these models to changes in capital. In particular, we would like to be able to sense the ability of capital and labor to substitute for one another which implies a negative relationship between the labor and capital components of a fixed capability weapon system.

Unfortunately, because of the coverage deficiencies noted earlier, the functional relationship between labor and capital is invariably positive: that is, more capital generally calls forth more labor. Figure 3-1 shows the major theoretical issues involved in this type of sensitivity. The isoquant curve is a locus of capital (K) and labor (N) combinations which are capable of producing a fixed output. As you move along the isoquant, the quality of the capital stock (and, of course, the quality of the labor) changes. A capital intensive system can be expected to look and operate much different from a labor intensive system--and the same is true of the labor required to drive the system.

The budget constraint is a line connecting the maximum amounts of labor (N_o) and capital (K_o) which could be purchased with a given budget. As such, its slope, $|K_o/N_o|$, conveys the relative factor prices of capital

Figure 3-1. Idealized Iso-production Curves

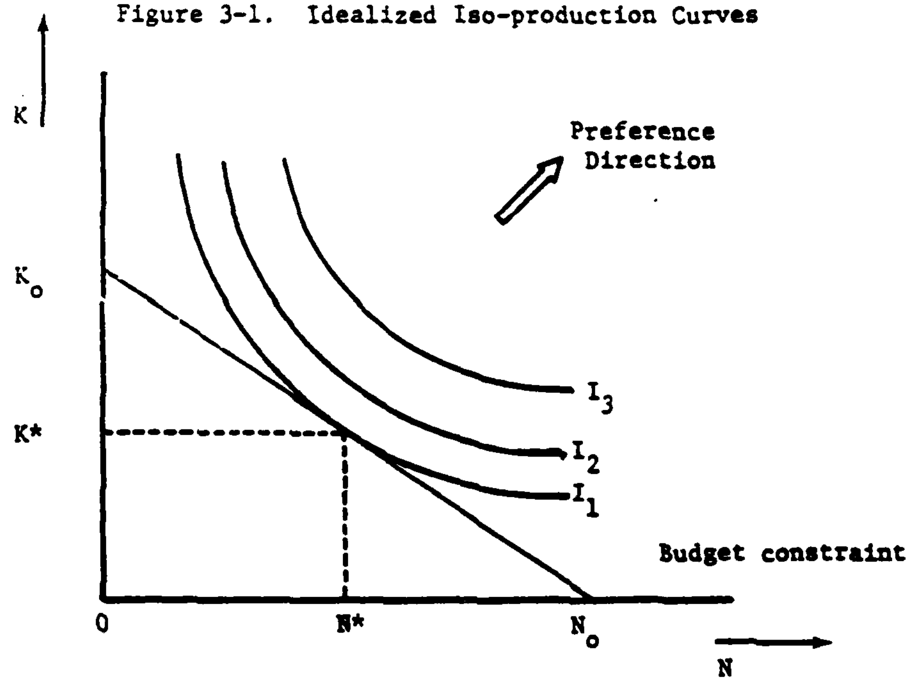
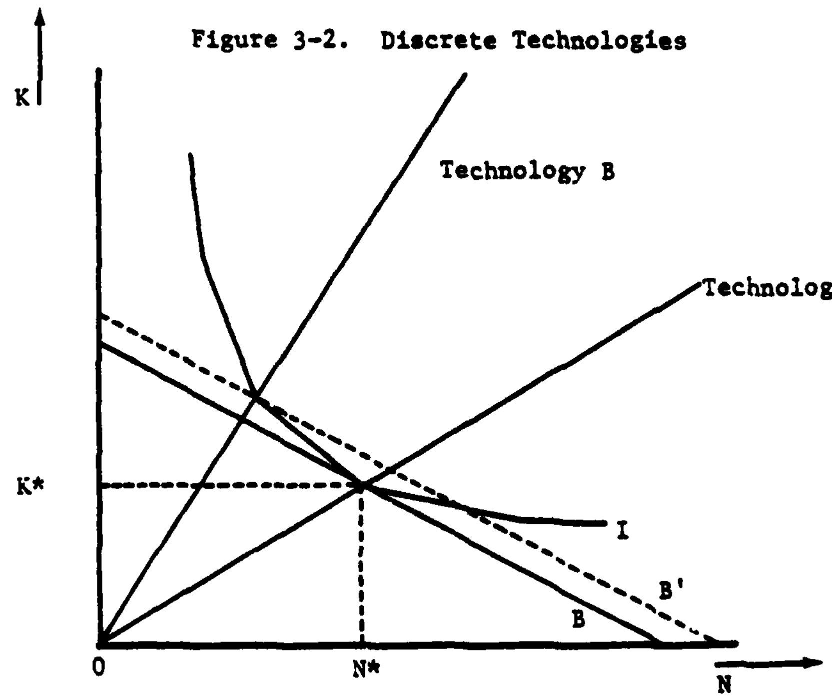


Figure 3-2. Discrete Technologies



and labor. As the price of labor rises compared to that of capital (the budget constraint rotates in a clockwise fashion) the point of tangency between the budget constraint and the isoquant moves upward along the latter. Since that tangency indicates the combination of factors which maximizes output for a given budget, the combination K^*, N^* represents an optimal factor mix.

We would not really want a cost model, for an individual system or equipment, that reflected the kind of continuous tradeoff portayed by Figure 3-1, however.

The smooth (continuously differentiable) isoquant shown in the figure is quite unrealistic. There might only be three or four points on the curve which are actually defined by real collections of labor and capital. Those points, shown more clearly by Figure 3-2 can be thought of as technologies. The rays from the origin passing through those points (A and B) are geometric representations of the capital labor ratio associated with each technology. In the case of Figure 3-2, the labor intensive technology, A, is the most advantageous: to reach the same output along B, more of both labor and capital would be required.*

---

* This need not be an optimal solution. Some economists argue that optimality can be achieved in such a discrete environment by combining technologies. That is one sector might use technology A and another technology B. The distribution of labor and capital between the two would be predicated on the difference between factor prices and productivity in the dominant sector: the other sector would use residual amounts of both factors. See, for example, H. J. Bruton, *The Principles of Development Economics*, Prentice-Hall, Englewood Cliffs, 1965, pp. 25-30.

The problem of demonstrating capital labor tradeoffs through the medium of cost models is very closely related to the discrete isoquant of Figure 3-2. The kinds of tradeoffs likely to have an impact on labor requirements tend to be large perturbations in the cost of capital. Two such changes would be the introduction of full built-in test (BITE) capability or a change in repair philosophy to discard at failure. In both cases, the cost of labor is lowered significantly by the elimination of much of the training cost for maintenance personnel as well as a decrease in labor hours required. Hardware costs also rise, however. The addition of full-blown BITE capability can easily increase the cost of a system by fifty percent while a switch to discard at failure from a repair posture will increase the amount of spares required by a system, usually by several times the normal allowance quantity.

The choice of two capital labor tradeoffs related to maintenance is symptomatic of the most significant finding of this study: while most models treat maintenance labor, few deal with operator labor. Yet, the total cost of operators is much higher (because there are more of them) than that of maintainers. In particular, most of the best models used in the Navy are level of repair (LOR) models. These are actually tradeoff tools which ideally allow the analyst to investigate the costs and returns associated with repair policy or posture. The basic decision is between repairing a part when it fails or simply discarding it. If the decision is to repair, then the echelon at which it is least costly to do so should be determined. These are the organizational, intermediate,

or depot levels (hence, level of repair). The capital labor tradeoff is implicit in the data set used to drive such models. For example, if an equipment is to be discarded, repair training is dispensed with, spares costs are increased and depot equipment costs are reduced. Similarly, the use of BITE increases the costs of spares since there is now more equipment, but reduces the cost of external support and test equipment and reduces the cost of training. But since most level of repair models focus only on the operating and support phase of a system's life cycle, the large increase in acquisition cost associated with BITE can easily be ignored. One suspects that this oversight occurs during the specification writing stage of the WSAP as well as later and that BITE is, as a consequence, frequently specified where it should not be. This and a range of associated problems will be discussed at more length in the conclusions section. For the moment, the idea of a level of repair tradeoff leads to another question, explicitly addressed by the HARDMAN study: that of tradeoffs between types of labor.

3.2 Labor Cost Response to Labor Type Substitution

While capital labor tradeoffs can be convoluted as a result of the role of technology, labor-labor tradeoffs are more straightforward. The Navy has the option to buy labor in four distinct forms. These are military, civil service, contract hire and as value added. The first two are familiar. Contract hires are civilian employees of private firms who are paid by those firms to perform personal services for the Navy. Labor is purchased as value added when the Navy purchases goods which, including a

component of labor, are able to substitute for another type of Navy labor. The most convenient example is the purchase, at a flat rate, of a component repair. The Navy may, for example, set up a basic ordering agreement (BOA) with a firm to perform repairs on failed printed circuit boards. For a flat rate, say $400 per repair, the firm then guarantees to repair (or replace) any board it receives during the normal life of the system. The gain to the Navy is in elimination of all costs associated with owning and operating a repair facility, a large component of which is labor cost.

There is nothing new about the purchase of labor services through value added. Over the years the Navy has relied more and more heavily on private firms for the production of hardware. The value added component of such purchases is very large. While it has become normal practice to purchase new equipment outside the Navy, there is still considerable resistance to the purchase of such things as equipment repairs which include such obviously large labor components. We would speculate, with Cooper, that this view is partly a hangover from the era of the draft in which a very healthy discount was available to the services for using military labor instead of civilian labor.* The validity of ignoring this potential tradeoff (between value added labor and other labor types) in the presence of an all-volunteer force (AVF) is at least questionable.

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* *Military Manpower and the All-Volunteer Force*, R-1450-ARPA, The Rand Corporation, Santa Monica, 1977. See particularly the discussion of civilianization, pp. 292-303. Note, however, that Cooper does not deal with the value-added form of labor purchase since he is interested solely in explicit manpower issues. He restricts himself to the first three forms of labor mentioned here.

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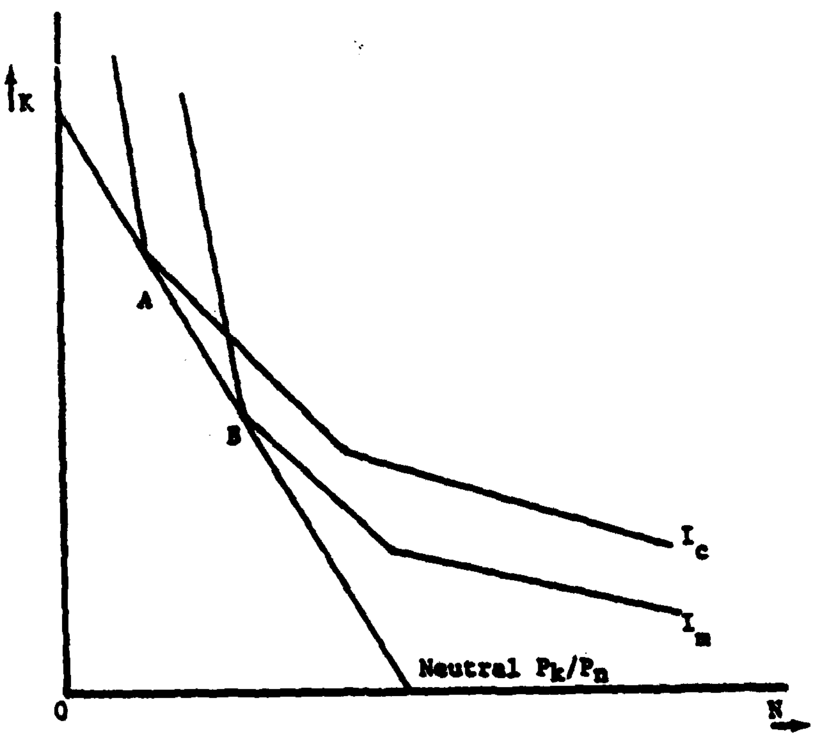
With the advent of the AVF, the Navy has found it necessary to compensate servicemen at roughly the same rate as their civilian counterparts. Early experience, in fact, has sometimes led to total compensation packages which, for a particular age and education cohort, are greater than civilian earnings. Making the assumption that military compensation rates are an adequate reflection of a competitive labor market, however, we can ignore the possibility that direct labor costs are significantly different in the two sectors. As a consequence, the rates of return to the use of the two types of labor are functions of relative productivity. The productivity of labor in the two sectors will, in turn, be related primarily to the capital stock available to each group and thereafter to other factors of production such as management expertise.

The relative productivity of the two groups could be compared with a graph similar to Figure 3-2, but which included two different iso-production functions. One of these would be for combinations of labor and capital in the private sector and the other for combinations in the military sector. A hypothetical example is shown in Figure 3-3. The curve I_c is the civilian isoquant and I_m is the military isoquant. They are both descriptive of the same output level and therefore portray differing abilities of the two sectors to combine capital and labor (and other factors of production) to produce output. The budget constraint passing through points A and B is descriptive of a neutral relative wage between labor and capital: that is, the relative prices of the two factors of production are such that either sector can produce the same output at the same cost. A higher

Figure 3-3. Isoquants for Dissimilar Sectors



wage rate (rotating the budget constraint clockwise) would mean that only a lower output could be achieved on the family of I_m curves if the budget constraint still passed through A. The implication is that all production of the good in question would occur in the civilian sector, barring non-economic reasons for continued military production. The converse is also true: if the relative cost of capital rose, then all production would shift to the military sector.

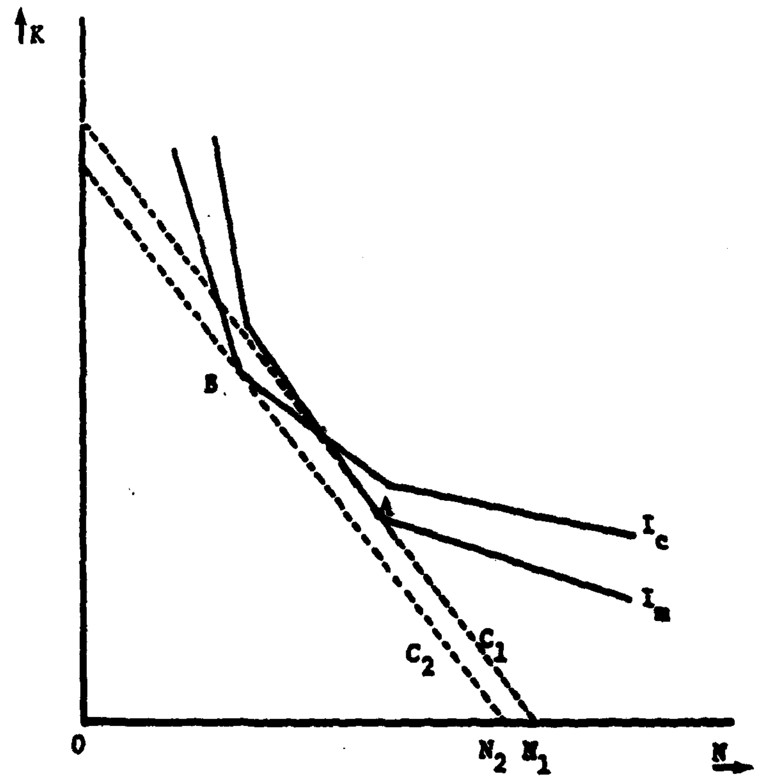
Because all institutions change slowly and because the Navy has only a short experience with the AVF, it seems reasonable to assume that the real situation is close to that portrayed by Figure 3-3: that the capital stock and management expertise of the Navy are geared toward a labor-intensive environment compared to the civilian sector. Shifting production, therefore, to the civilian sector would provide a simple gain by decreasing the cost of achieving the same output. This alternative is shown in Figure 3-4. By shifting from A on I_m to B on I_c, the same output is achieved at a smaller budget level, C_2. The savings are graphically portrayed as the labor cost associated with $N_1 - N_2$ labor units.*

3.3 Implications for Modeling

The importance of both capital/labor or labor-type tradeoffs implies the need to reflect these tradeoffs in the structure of cost models. In

* The reader should bear in mind that our purpose here is *not* to make the policy recommendation that all military production be shifted to the private sector. Instead, this hypothetical example is constructed to illustrate the importance of measuring such differences with regard to those elements of life cycle cost in which a choice is available.

Figure 3-4. The Gain from Shifting Sectors



considering the acquisition of capital there are two ways this must be done. The most familiar is to allow tradeoffs within the operating and support era of the life cycle. Another important kind of tradeoff, however, is the inter-temporal exchange of costs between acquisition and support. The folk wisdom of the life cycle cost community has been that low acquisition costs have traditionally been purchased at the expense of excessive operating and support costs. While this may have been true in the past, exclusive concentration of analytic attention on the operating and support era merely exchanges one problem for another. Therefore, all cost models must be capable of reflecting inter-temporal tradeoffs.

A too literal interpretation of the foregoing discussion would be that cost models must include mathematical statements--such as a Cobb-Douglas production function--which explicitly portray substitutability between capital and labor. While such structures could be formulated, their value in system design is unclear. In economics they are used as descriptive rather than creative tools. The task of design is a creative one, tied to the existence of limited numbers of feasible approaches in which the decisionmaker is, at best, uncertain of the capital/labor substitution possibilities implicit in his options.

The appropriate structures then, should not be formulated as ways to explicitly capture factor substitution. Instead, they must accommodate the elements of cost germane to both capital and labor intensive outcomes. The result will be that any system will be adequately costed: design alternatives will show the impact of capital/labor substitution as it is

impounded in the design. The general principle involved is sufficiently important to warrant some further discussion.

Cost models to be used in the design of a weapon system must be driven by the variables which the designer is competent to deal with. Institutional or technical knowledge outside his scope must be captured in the structure and parameters of the model. In other words, the variables he uses to drive the model must be policy variables for him--variables over which he has control and can exercise professional discretion.

To reduce the general argument to specific terms, the cost model must be driven by technical design variables. In addition, the structure must correctly account for both labor and capital. To correctly account for these costs means two things: extent of coverage and accounting for the influence of time. Both of these requirements were discussed at length in Chapter 2.

4.0 PARAMETRIC COST ESTIMATING METHODS

There are three general types of cost models insofar as mathematical structure is concerned. They are parametric models, process models and accounting models. Each has different strengths and weaknesses, and each approaches the two problems of cost *estimation* and cost *analysis* from a distinct point of view. This chapter discusses parametric methods and contrasts them to process models.

This chapter consists of a general introduction to parametric models. Section 4.1 is an introduction to the theory and practice of CER's; Section 4.2 discusses the utility of parametric models as trade-off tools using examples drawn from two models, the Naval Aircraft Operating and Support Cost Model and the Advanced Naval Vehicle Individual Life-Cycle Cost Model (ANVIL).* Our conclusions are presented in Section 4.3.

4.1 Cost Estimating Relationships

A CER is a mathematical relationship, derived from historical data, between the cost of something and one or more of its quantifiable characteristics. The simplest form of such a relationship is $C = aX$, where C is cost, X is a measurable characteristic, and a is a parameter which is determined through regression analysis, a statistical technique

* Administrative Sciences Corporation, "Naval Aircraft Operating and Support Cost Model - FY76 Revision," ASC R-116. March 1978 (OP-96D) and Noah, J., et al, "Advanced Naval Vehicle Individual Life-Cycle Cost Model," J. Watson Noah, Inc. May 1978 (OP-96V).

for estimating the parameters of the curve which best fits a set of simultaneous observations of two or more variables. The variable X can represent weight, volume, size or any other quantifiable characteristic. A CER can also be a multi-valued function of several independent variables. In some cases, a "dummy" variable might be used, its value set to either zero or one, depending on the presence or absence of some (usually non-quantifiable) characteristic. For example, another form of CER would be $C = a + bX + cL$. The variable X is a measureable characteristic of the equipment; L is a dummy variable set equal to one if large scale integration (LSI) technology is used, otherwise it is set equal to zero. The values a, b and c are parameters determined by regression analysis. Each of the parameters have a specific meaning: a is the C intercept of the regression line, b is its slope, and c is the vertical shift that occurs when LSI technology is present. Figure 4-1 is a graph of the equation.

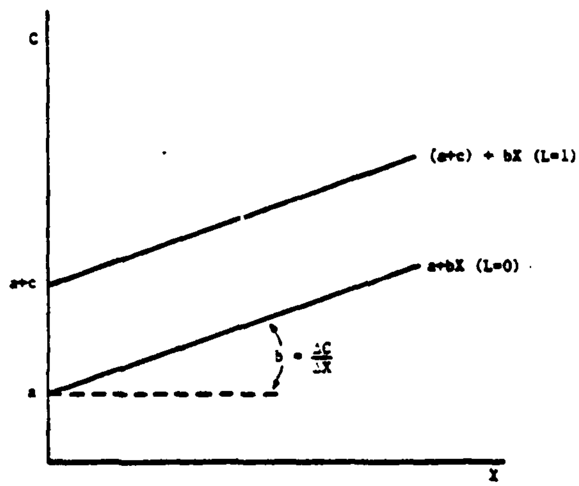


Figure 4-1. $C = a + bX + cL$

Basic forms of CER's include linear, quadratic, semi-log, log-log, and exponential. Each portrays a different fundamental relationship between increases in cost and changes in the variable or variables. The choice of which type of CER to apply to a particular set of observations should be related to some theoretical model of the causal relationships between the dependent and independent variables.

As a specific example of how CER's are derived and used, let us take the following case.* In order to estimate the cost of aircraft engine overhauls, the data presented in Table 4-1 were collected. Figure 4-2 is a scatter plot of the data.

That these particular variables were collected reveals some of the analyst's implicit assumptions. Based upon some understanding of what goes on when an engine is overhauled, the analyst believes that the overhaul cost is largely determined by the diameter of the engine. The use of a turbofan dummy indicates that the analyst believes that the presence or absence of a turbofan is also an important cost driver.**

The next step is to decide what form of CER to use to estimate the data base. This too should be based on some notion or model of the processes involved in overhauling aircraft engines.

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* Administration Sciences Corporation, *op. cit.*, Table A-6, p. 39.

** Bear in mind, however, that *this is a finished data set*. The analyst may well have collected a large number of variables, searched among them for strong correlation with cost and published only those found to be well correlated. This poses a problem in interpretation of results which is discussed below.

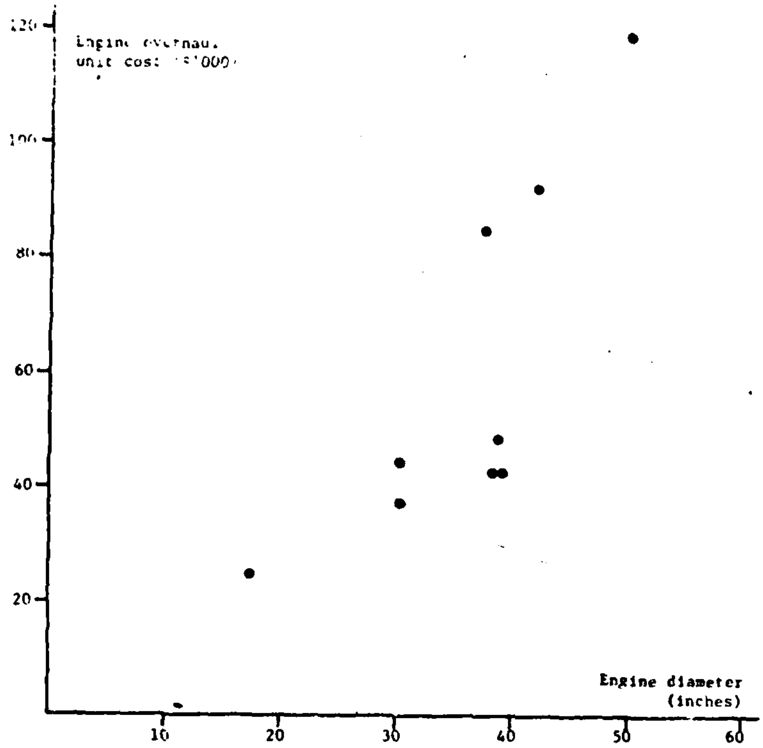

Fig. 4-2 Engine Overhaul Cost as a Function of Engine Diameter

Engine	Average Unit Overhaul Cost	Turbofan Dummy	Diameter (Inches)
J52-P8B	37.8	0	30.2
J52-P408	44.6	0	30.2
J57-P10	48.8	0	38.9
J79-GE8	42.6	0	38.3
J79-GE10	42.6	0	39.1
TF30-P408	92.3	1	42.0
TF30-P412A	118.7	1	50.0
J85-GE4A	25.6	0	17.7
TF41-A2	85.4	1	37.5

Table 4-1 Data Base for Engine Overhaul CER Development

Suppose, as an example, that the main task involved in overhauling an engine consisted of spraying a protective coating on the cowling of the engine. One would expect the labor and materials cost of engine overhaul to be a function of cowling surface area. That is, cost would be expected to increase as the product of the length of the engine and the square of its diameter. In this case, one would set forth the hypothesis that engine overhaul costs could be adequately estimated by the equation $EO = aD^2L$, where EO is the cost of an engine overhaul, L is the engine length, D its diameter, and a is a parameter whose value will be estimated by statistical analysis of historical data. Once the value of a has been determined, other statistical tests can be used to see whether the hypothesis is "acceptable."

This, anyway, is the way the process of statistical inference should be carried out. Unfortunately, it is sometimes the case in cost analysis that, lacking any theoretical structure from which to draw causal models, we are forced to a more deductive process. This usually consists of collecting as much data as possible (a very expensive process), and then sequentially testing all the independent variables against one another, trying to find a "good fit." The result is sometimes statistically impressive, but rarely causally valid. Strauch provides a careful statement of our objection to the process: "I am not condemning the use of statistical techniques to 'snoop' through large amounts of data to look for possible interesting relationships worthy of further study. Such

'snooping,' however, is not statistical inference, and relationships thus found should not be treated as though it were."*

In the case of the engine overhaul cost, it was decided that the appropriate model is linear of the form EO = a + bT + cD, where EO is the unit cost of an engine overhaul in thousands of dollars, T is a turbofan dummy variable (one if the engine is a turbofan, otherwise zero), D is the engine diameter in inches, and a, b, and c are parameters whose values will be estimated by regression analysis. Using a statistical technique called multiple linear regression, the following CER was derived:

$$EO = 1.09 + 45.06T + 1.21D. \quad **$$

Using this equation, one would estimate, for example, that the engine overhaul cost for a 45" diameter turbofan engine would be $100,600. A graph of the data points and regression lines is presented in Figure 4-3.

* Strauch, R., "Some Thoughts on the Use and Misuse of Statistical Inference," Policy Sciences, Vol. 1, 1970 fn. p. 88.

** The basic idea behind regression analysis is to find the line "closest" to all of the data points. This is accomplished mathematically by solving a set of equations which yields the parameters of a line such that the sum of the squares of the vertical distances between the line and each data point is a minimum. Different regression routines invariably produce slightly different parameters. For example, when we ran our own regression analysis on the data, we obtained the following equation: EO = 1.27 + 45.49T + 1.21D. Almost any elementary statistics text will include an exposition of regression analysis. See, for example, Hall, P., *Introduction to Mathematical Statistics*, Wiley, New York, 1962, Chapter 7.

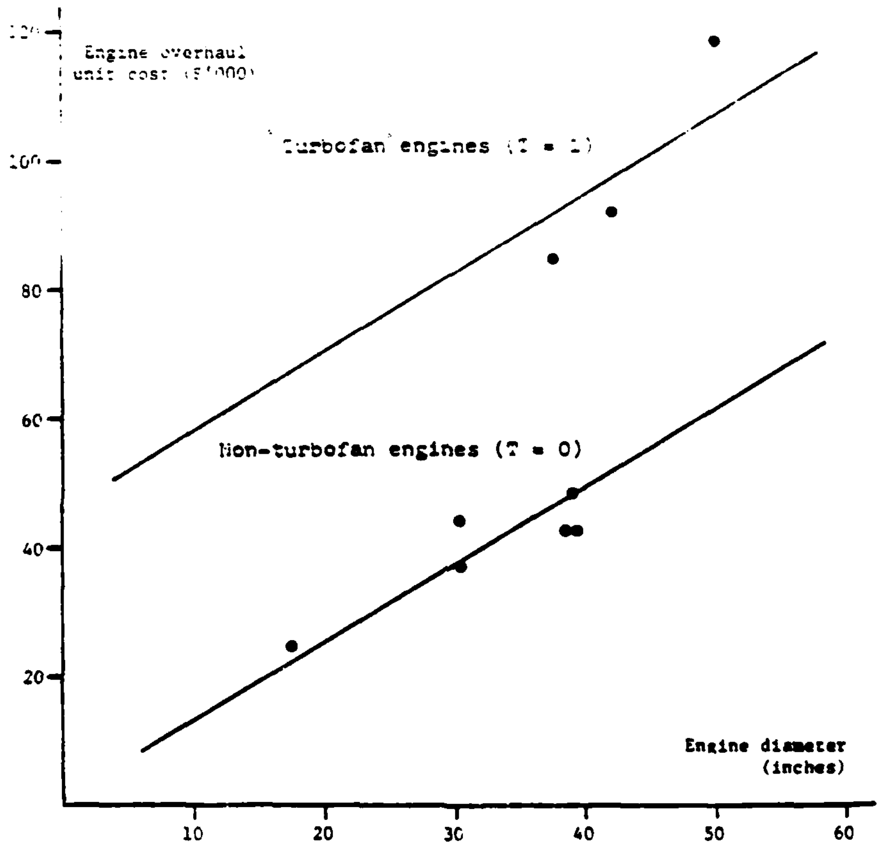

Figure 4-3. Engine Overhaul Cost Estimating Relationship
$EO = 1.01 + 45.06T + 1.21\ D$

Having derived the CER, it is well to ask how useful or reliable an estimator it would be. Specifically, we must check three things. First, we must test the underlying assumption of the CER that the cost of an engine overhaul is in fact a linear function of the engine diameter and the absence or presence of a turbofan. Assuming it *is* linear, we can then check to see how well the parameters have been

estimated. Finally, if both of these tests have satisfactory outcomes, we can test the ability of the equation to pick up variations in the dependent variable.

The first two of these three questions are addressed by tests of hypothesis. This consists of establishing an hypothesis for each question and checking to see if the hypothesis can be rejected on the basis of measured data. Notice that, technically, no hypothesis can be *accepted*: the classical theory of statistics makes no provision for acceptance since that would be tantamount to establishing a law on the basis of a simple experiment.* At a second stage, the decision maker may well be willing to act *as if* some hypothesis were true, even though it could only have been shown to be not false. To check for linearity we define the null hypothesis that the relationship between the independent variables (engine diameter and presence or absence of a turbofan) and the dependent variable (overhaul cost) is not linear. A statistical technique called the F-test is used to test this hypothesis. A

*Statistical hypothesis testing is possibly the most abused and poorly understood tool used by social scientists. Extreme care must be taken in formulating statements of conclusions - and *pari passu* in formulating the hypothesis to be tested. For a fuller discussion of problems in statistical inference, see Strauch, R., *op. cit.*, p. 87 ff. A more permissive and very concise statement on useful hypothesis formulation may be found in Graybill, F., *An Introduction to Linear Statistical Models*, Volume I, McGraw-Hill, New York, 1961, Section 2.5, pp. 39-41.

computation of F from the data can be compared to tabled values of the appropriate F distribution. If the former is greater than the latter (at whatever confidence level one chooses), we can reject the null hypothesis. In our example, the calculated F was 76.1, which corresponds to a confidence level of 99.9945 per cent. Thus, the null hypothesis of no linearity can be rejected with considerable (statistical) confidence.

The validity of the parameter estimates (b and c) can be tested by reference to the theoretical distribution of the t statistic.* Again, by comparing calculated values of t to tabled values from the theoretical distribution, one can test the null hypothesis that the slope coefficients are zero. The null can be rejected in both cases (i.e., the parameter estimates are robust): the confidence levels are 99.99 percent and 99.45 percent for b and c respectively.

To test the explanatory power of the whole equation, we use the coefficient of multiple correlation or, more simply, the R^2 statistic. R^2 measures the amount of variation in the dependent variable which is mirrored by variation in all the independent variables. It can be read as a percentage. The R^2 value for this particular relation is .949 or 94.9 percent. Altogether,

*The t- and F-tests are related. See the treatment in Goldberger, A., *Econometric Theory*, Wiley, New York, 1964, pp. 108-9. See also pp. 192-4 for a rigorous treatment of multicollinearity (the problem indicated by low t values in the presence of high F ratios).

these three tests indicate an extremely strong relationship "explaining" engine overhaul costs for Navy jet aircraft. Moreover, the implication of a real causal relationship between engine intake diameter and overhaul cost seems intuitively acceptable.

4.2 Parametric Models as Trade-Off Tools

Parametric models possess many qualities useful to cost analysts. They can be, and are, used early in the acquisition process. Once the CER's have been derived, the models require relatively little data to run and therefore can be run quickly and cheaply. Most importantly, parametric models are often used simply because no other technique is available. This is especially true in the earliest periods of the WSAP, at the very beginning of the design process. Unfortunately, very few models are available which can be applied earlier than this. That is, few use operational capability as their input variables.*

*One that does is a gross parametric model used at Northrop, Aircraft Division. We would like to thank Herb Harris, head of the life cycle cost group there for a description of the model. The Northrop model is proprietary as are most others driven by operational variables.
** In statistical terms, this requirement is stated as follows: the data base must consist of independent, random samples drawn from a population whose frequency distribution remains constant. If any of the assumptions implicit in our equation are not true of a new equipment, the CER will not perform as well for that equipment as the statistical tests of the CER would lead us to expect.

The Critical Assumption Error

The true test of any cost model is its ability to predict costs adequately - and the user's confidence in the model's predictions. While statistical tests such as those applied in the previous section appear to provide all the information one would want as to the accuracy and reliability of the cost estimates, the fact is their application is invalidated if one stringent requirement is not met: that each equipment to which the CER is applied possess all the cost-relevant characteristics which characterized equipments in the data base but aren't treated explicitly in the model.** One can show statistically, for example, that there is a strong correlation between the number of cars driven in a city on a particular day and the sulfate level of the air. However, in between the independent and response variables is a myriad of intervening factors. Unless one can be certain that these hidden factors remain constant between applications of the regression equation, one can have no confidence in the accuracy of the estimates: a relation for the level of sulfate in the air derived from data collected in Los Angeles will not be accurate if applied to New York, because the conditioning geophysical environments are different. It is similarly obvious that the CER explored earlier would not work very well for engine overhaul in Air Force facilities. However, it is less clear that the relationship might break down as a consequence of a change in

support policy - or even more likely, due to a change in cost accounting practices at Naval Air Re-Work Facilities. These "hidden" assumptions are only examples of many potential factors which could influence the applicability of the CER to a new design.

The analyst who wishes to apply a CER to his project with any confidence will first have to assure himself that the general characteristics of the new equipment match those of the equipments used to derive the CER. This is very difficult to do, since these characteristics are hidden in the intervening factors compounded in the CER. Even if the data set used to derive the CER is available for inspection as part of the documentation of the model, it would be hard to interpret the information gained because the analyst can not know how or if the original data were "massaged." This practice - suppressing outliers, making subsidiary computations, adjusting index number series and the like - is both common and difficult to justify. The primary result is to make duplication of results impossible. By the same token, application of the model to new data will yield imprecise answers. The net result of undocumented data massaging is that the underlying assumptions behind the CER become unknown and unknowable to the user.

There are many different ways in which the intervening variables or critical assumptions can be invalidated for a new

equipment. Technology advance and changes in support policy, for example, will quickly render CER's obsolete. The Naval Aircraft Operating and Support Cost Model, for example, was developed in 1974, updated in 1975, updated again in 1976, and will require continual periodic updating to keep it current. This updating is not a minor matter. New data must be collected, all the equations must be rederived by regression analysis (not a mechanical process, but rather one requiring considerable cost analytic expertise), and the model must be redocumented and partially or completely reprogrammed. All this is extremely expensive and time consuming, and must occur before the model is applied to any specific project.

A quote from the ANVIL model documentation further elucidates our point about critical assumptions:

> The CERs developed for Operation, Maintenance and Major Support were based on O&S cost data for currently programmed ships and aircraft. As a result, the cost estimates of these activities for advanced Navy Vehicles do not reflect some of the cost savings which may be achieved with discriminating operating, maintenance, and logistics philosophies that vehicle designers may have envisioned.*

The designer may actually be toying with concepts that directly contradict the assumptions of the CER. For example, he may be trying to build a small, extremely powerful engine that may require specialized, and expensive, maintenance. A CER which states in effect "the smaller,

* Noah, J., *op. cit.*, p. IX-6.

the cheaper" would be of no use to him.*

Specific application of the model creates a new set of problems. It is generally true that the less restricted the population sampled to derive a CER, the less reliable the CER is likely to be when applied to any specific case. Stating this the other way round, a CER built up from a very specialized data base might be quite accurate when applied to equipments which meet all the specifications of the equipments in the data base and very inaccurate once one strays from those specifications. More powerfully, one can state that a CER derived from a more generalized data base is not likely to be very accurate under any circumstances. Thus, in most cases, the analyst must bear the cost of developing a sufficiently specific CER which would be useless in other applications, or accept a too general CER that will provide inaccurate estimates.

Dynamic Range

An additional problem is created by the limited dynamic range of many CER's. The engine overhaul CER discussed in the previous section provides an excellent example. As one might expect, it is very sensitive to changes in outliers. Figure 4-4 shows the effect on the regression line of removing data points associated with the

* It may be the case that the CER is indeed an inviolable rule applicable to certain classes of aircraft engines, or perhaps even to all engines. The point is, we have no way of knowing this and every reason to doubt it.

smallest and largest engine diameters (lines a and b, respectively). While the impact on cost estimates would be relatively small in the middle range of engine diameters (30"-40") it is increasingly significant as engine diameters become much larger or smaller. This indicates that one should be even more hesitant than usual about extrapolating values from the CER beyond the middle range of diameters found in the data base.

To illustrate the point numerically, imagine that the smallest engine (the J85-GE4A) had not yet been built. The data set would therefore lack this point, and the regression line would look like the one labeled a in Figure 4-4. Application of the CER to the estimated diameter of 17.7 inches yields an overhaul cost estimate of $16.5 thousand dollars: $9 thousand dollars less than the actual cost of $25.6 thousand. To put this in other terms, the "overrun" would amount to more than 55 percent. Making the same computation for the largest engine, the TF30-P412A, yields an overrun of 21 percent.

To digress briefly, we can illustrate the possibilities inherent in choosing different functional forms. We tested the same data against the exponential form, $EO = ae^{bD}$, and the simple linear form, $EO = a + bD$. Figure 4-5 presents a graph of the two regression lines.

Both forms ignore the distinction between turbofan and other engines (i.e., are more general) and, accordingly, suffer:

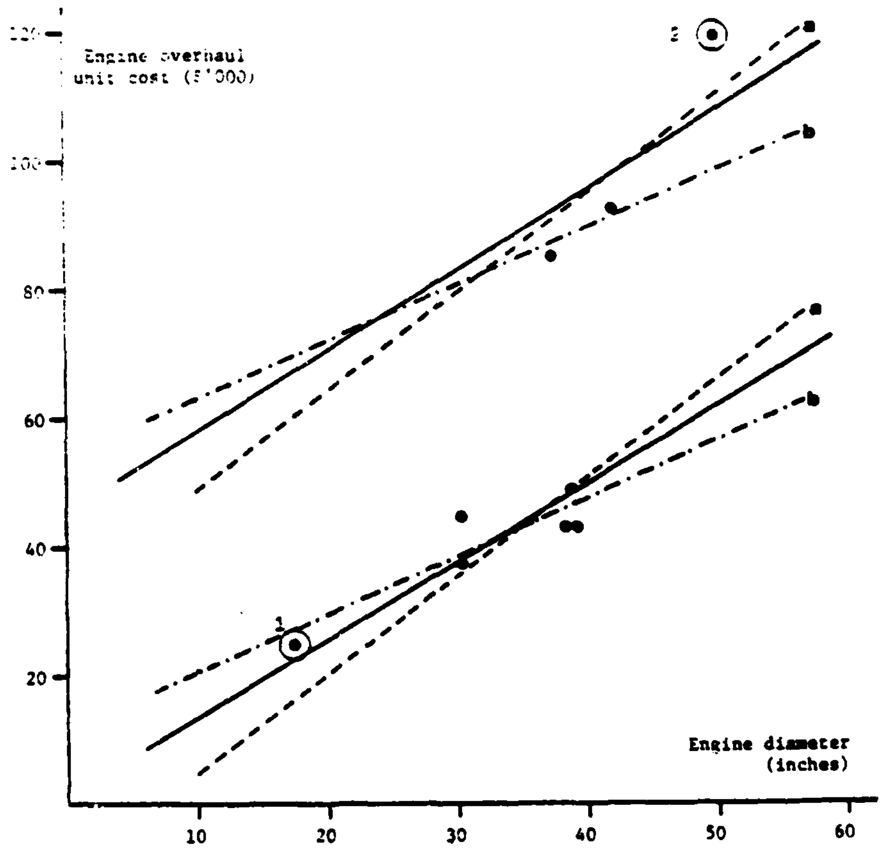

Fig. 4-4 CER Outlier Sensitivity

original regression line: EO = 1.01 +45.06T + 1.21D R^2 = .94

a point 1 removed: EO =-10.38 + 43.64T + 1.52D R^2 = .95

b point 2 removed: EO = 12.09 + 42.11T + .87D R^2 = .98

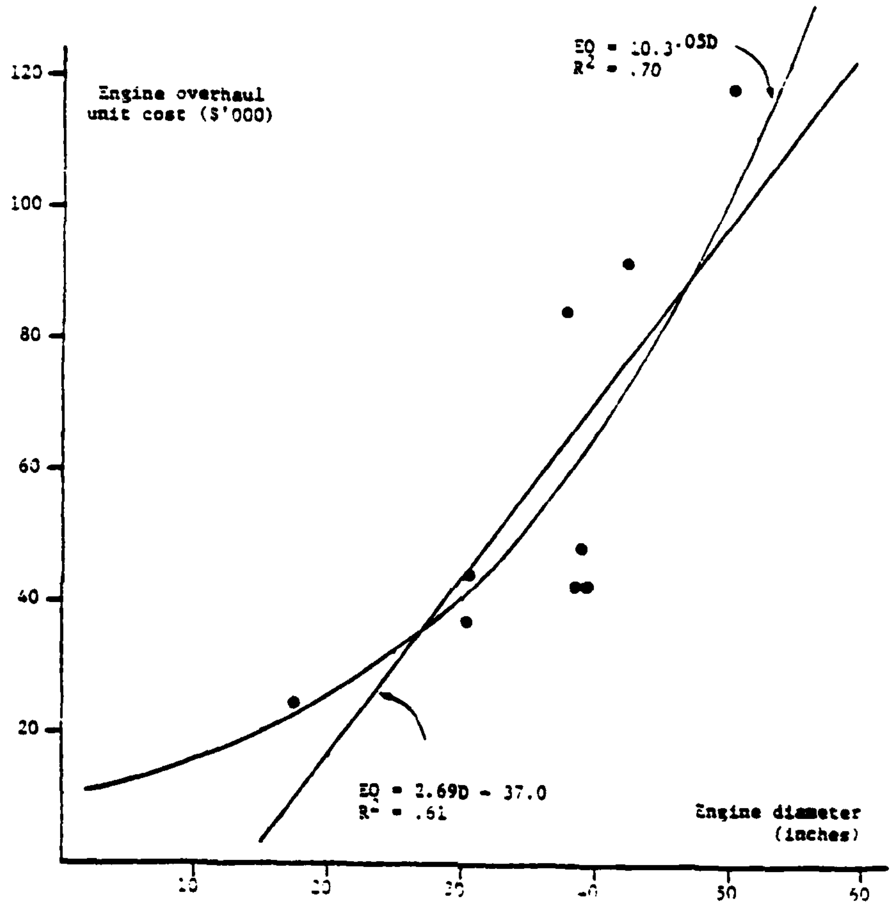

Figure 4-5. Two Alternative Models to Fit Engine Overhaul Cost Data

the R^2 drops to 70 percent for the exponential form and 61 percent for the linear. The exponential form, however, is less sensitive to outliers than the other forms. Subjected to the same experiments which yielded hypothetical overruns of 55 and 21 percent in the

two-variable linear version, this form produced overruns of 30 percent in both cases. The actual dollar errors (absolute differences) were smaller by several thousand dollars. Our quandary, of course, is that we have no *ex ante* reason for choosing any one of the forms because there is no "extraneous information" in the sense this term is used by Goldberger: "it comes from outside the sample itself."* Thus, we fall back on rote acceptance of a "good" fit.

Policy Variables

The final, and perhaps most difficult, problem with CER models used as tools of tradeoff analysis is their frequent inability to address "policy" variables. A policy variable measures something over which a user exercises discretion - about which he wishes to make a decision based on the cost of choosing different values. A design engineer might, therefore, find the engine overhaul equation useful since, presumably, he is free (within some range) to alter the diameter of his engine's design.** Someone interested in developing

* *Op. cit.*, p. 255.

**Even this provides a conceptual trap. For example, it may well be that while the engineer can alter the diameter of his design, doing so will have the opposite effect from the one predicted: overhaul costs will rise. In fact, it is generally the case that the predictive value of such models is destroyed when the designer operates on independent variables. That is, the independents are proxies for the real cost generators - they are only good proxies if they are allowed to arise naturally from a design process which ignores them.

operational specifications for the engine, however, could not use the equation unless he knew how to convert *his* policy variables - speed, rate of climb, payload, range, etc. - into engine diameter.

If the only feasible CERs use technical characteristics as independent variables, then they are of little utility in the earliest stages of the WSAP, when operational requirements are being specified. It appears that certain transformation relationships *can* be developed so that the appropriate policy variables can be used. The Northrop model mentioned earlier is an example. Yet, this has not generally been done and may be infeasible for government use. Northrop (or any other firm) can create CERs - for acquisition cost only - of intra-company utility because most of the intervening variables have to do with the way Northrop builds airplanes. But there is great dissimilarity between the way Northrop builds aircraft and, for example, the way Grumman does. That is, the critical assumptions won't hold from one case to another.

If the required transforms are infeasible, then at least we can use technical CERs at a later stage of the WSAP - when the data begin to become available. The point here is that if those data *are* available, then we can also use process models, at least for the operating and support component of life cycle cost. And since process models can be formulated to deal specifically with the policy variables germane to manpower-hardware trade-offs, we prefer them to CERs.

4.3 Appropriate Use of Parametric Methods

In Section 4.2, three generic classes of problems associated with the use of parametric models as trade-off tools were introduced. These included problems associated with critical assumptions, dynamic range, and policy variables. The critical assumptions error deals with the hidden, intervening factors which are compounded in CER formulations. Two of its most important effects are lack of confidence when applying parametric models to new equipments and the necessity of continually updating and rederiving CERs. Problems in dynamic range occur when a CER is applied to a specific project: the range of values for which the CER is reliable may not be appropriate to the particular project. Problems involving policy variables may occur when a parametric model is used as a trade-off tool: the independent variables used in the model seldom directly address the policy options of interest to the user.

The implication of these problems is that the designer or project manager wishing to use a parametric model for conducting trade-off analysis would have to have a special model developed for his specific and one-time needs. This is 1) extremely expensive; 2) in conflict with the desire of NAVMAT (as expressed by NWESA) to discourage the independent development of one-time cost models; and 3) in conflict with the desire of the HARDMAN office to develop uniform guidelines for conducting hardware-manpower trade-off analyses. For these reasons we recommend against the

use of parametric models as trade-off tools.

Where, then, do parametric models fit in the WSAP? The most appropriate application appears to be for estimation of acquisition costs as soon as the rough technical characteristics become measurable. Thereafter, these models can be used to monitor acquisition costs with greater and greater fidelity (through increasingly complex formulations) throughout the remainder of the WSAP. For the prediction and analysis of operating and support costs (including virtually all manpower costs), process models are both more suitable and more reliable.

The essential mathematical difference between CERs and process models is that the latter are composed of identies, while the former are less precise, functional relationships. As intervening variables are removed from CERs, the latter approach the status of identies. While this is considered trivial in the study of social behavior, it enhances accuracy in cost analysis. The tremendous accuracy of some of the CERs in the Naval Aircraft Operation and Support Cost model is due to the use of near identies. See, for example, the equation for Other Deployed Manpower, on page . The R^2 is 98.3 percent, and t and F are extraordinarily high. The reason is that the equation is of the form $X = f(Q)$, where $X \equiv QP$. Thus, the regression parameters merely portray P. This equation rests exactly at the cusp between CER and process models. Had the same point been approached from process methods, P would have been an input variable, and Q either an input or somehow dependent on the technical characteristics of the aircraft.

AG-PR-A100-2

VOLUME III

REVIEW OF NAVY HARDWARE COST MODELS

by

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October 1978

Contract No. N00014-77-C-0809
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Submitted to:

Scientific Officer
Office of the Chief of Naval Operations
Department of the Navy
Washington, D.C. 20350

EXECUTIVE SUMMARY

A review was conducted of selected Navy life cycle cost models. Seven individual models were chosen, either on the basis of widespread use or because they were representative of a class of important models. The purpose of the review was to determine the usefulness of these models in conducting hardware/manpower cost tradeoff analysis during the weapon system acquisition process (WSAP).

The criteria for judgement included validity of the cost concept implied by a model's structure and the utility of the model as a tool for tradeoff analysis. Two other concerns were the usefulness of the software by which a model was implemented and the adaptability of the model to use in various stages of the WSAP. These topics are covered in detail in Volume II.

Assumptions regarding the treatment of overhead, the use of average or marginal cost and the treatment of opportunity cost were different in all the models, indicating a lack of clear policy guidance. Furthermore, many of the models displayed internal conflicts between some of these issues, indicating that the model builders themselves were ruled by no clear concept of cost. The extent of coverage was, with regard to manpower, uniformly poor. This was true despite, in some cases, tremendous complexity in aid of extremely small non-manpower cost elements.

The usefulness of the models as tools for tradeoff analysis was limited to comparisons of hardware alternatives. The uniform understatement of labor cost makes it impossible to measure factor substitutability without tremendous downward bias in the stated cost of labor. This is seen as a particularly unfortunate aspect of the models in view of what are known to have been substantial rises in the cost of labor compared to capital in the past few years. A related issue was the ability of models to reflect comparisons of labor in different forms such as military, general schedule and direct hire. The models were generally unable to make such comparisons since their structures were unsuitable. While capital labor tradeoff capability is simply a matter of enhancing methodology, labor type tradeoffs must await the resolution of a number of policy questions having to do with civilianization. This is necessary in order to develop appropriate structures for process modeling of civilian labor utilization.

Of all the models reviewed, only one was intended for the conceptual phase of the WSAP. Despite the intention, it did not appear generally useful for that purpose. All the other models are chiefly useful only after a relatively detailed design has been achieved.

A number of conclusions can be drawn, and policy implications suggested as a result of the findings of this study. With regard to the cost basis and objectives of the models, there is ample evidence to suggest that general purpose models/software are premature, given the state of the cost modeling art. In addition, the separation of models by different analytical tasks - life cycle cost analysis, level of repair analysis, and others - seems both spurious and counter productive. All such models are intended to do the same thing: measure life cycle cost. By the creation of different models for different analytical tasks, the Navy imposes a burden, not only on contractors engaged in design and development, but also on the Navy's own acquisition personnel. The burden is typified by inconsistent analysis and redundant data collection and reporting tasks, both inside and outside the Navy.

PREFACE

This volume of the Hardware/Manpower Cost Analysis Study presents the results of an intensive review of selected Navy costing methods. The role played by this review in the study as a whole was to provide a solid empirical basis, for both the theoretical discussion of Volume II and the guidelines of Volume I. The work reported here was carried out before that reported in the first two volumes, and therefore provided a departure point and a certain focus to what followed.

Our findings in reviewing these models suggested that, for whatever reasons, the development of cost analytic methods by and for the Navy has not benefited by any general, theoretical guidance. Volume II represents an attempt at providing such guidance, at least with regard to the analysis of manpower costs arising from hardware acquisition. This was the principal focusing influence of the review. Other effects included drawing our attention to certain modelling methods, emphasizing the need for at least some very simple cost models and thinking about the rate at which data demands can and should be imposed on a maturing system design.

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1.0 INTRODUCTION

As a first step in the development of guidelines for hardware/manpower cost analysis, a limited review of selected Navy cost models was undertaken. Rather than an exhaustive cataloguing of all Navy methodologies, the review consists of an intensive investigation of a few important models.*

The four main models published as Military Standard 1390-B, Level of Repair (Appendices) were chosen first because they are the only Navy cost methods published as a formal military standard. Second, they were chosen because they illustrate detailed process modelling as well as many of what

*For an exhaustive catalogue including many support cost models and model elements, see, "Catalog of Navy Systems Commands Systems Analysis/Operations Research Models," NAVFAC P-443, various editions. The publication contains brief descriptions and points of contact, but no critical review. Other reviews and descriptions are available, though most are not up to date. A relatively complete catalogue of logistics models up to 1971 is provided by Paulson, R., R. Waina and L. Zocks, *Using Logistics Models in System Design and Early Support Planning*, Rand, R-550-PR, 1971, Santa Monica. An updated version of this document, with a discussion of the geneology of current cost models is given in Butler, R., *Lectures on Cost and Logistics Analysis*, The Assessment Group, RD-107, 1977, Santa Monica. A catalogue of U.S. Army support cost models is provided by "Support Model Reference List," U.S. Army Maintenance Management Center, 1974, Lexington. A critical review of costing methods offered as a masters thesis at the Air Force Institute of Technology is given in Dover, L., and B. Oswald, Jr., *A Summary and Analysis of Selected Life Cycle Costing Techniques and Models*, Air University SLSR 18-74B, 1974, Wright-Patterson AFB. A critical review of several selected models and the field of cost modelling in general is provided by Collins, D., "Analysis of Available Life Cycle Cost Models and Actions Required to Increase Future Model Applications," Joint AFSC/AFLC Commander's Working Group on Life Cycle Cost, 1974, Wright Patterson AFB. Finally, a forthcoming review of Air Force life cycle cost methods is in K.E. Marks, *et al*, *Life Cycle Cost Estimation for USAF Aircraft Systems: An Appraisal of Cost Element Structures and Estimating Methodologies*, Rand, R-2287-AF, (1979), Santa Monica.

we consider to be the shortcomings of extant models. The Naval Weapons Engineering Support Activity (NWESA) Cost Guides for Equipments and Major Systems were chosen for review because of their wide currencv in the various systems commands. The SEAFIRE cost model was chosen as a representative program office life cycle cost model tailored for application to a particular procurement.

The models fall into two general categories: life cycle cost models and level of repair models. Life cvcle cost models, as the name implies, estimate the cost of an equipment or weapon system from the time of its first conception to the time it is scrapped. Level of repair models, on the other hand, are used to determine the least-cost support policy during the operating and support phase of the life cycle. These models therefore ignore acquisition costs.

Neither life cycle cost models nor level of repair models include *all* costs associated with an item. They are not budget allocation or bid estimation devices. It follows from this that the actual dollar values produced by these models are not nearly as important as the relative difference between the costs of two alternatives which are being compared using the models.

If a cost model is to be of value in reducing life cycle cost, it must be used as a *design tool*. This means it must be used early, often, and iteratively in the design phase of the WSAP. The most important criterion for evaluating cost models is therefore: is it used, or useful, in the design process? In particular, is it useful for conducting trade-

offs between hardware and manpower alternatives? A second criterion for evaluation is: useful as a design tool or not, does the model estimate costs--particularly manpower costs--correctly?

Chapter 2 provides a general review and description of the seven models. Chapter 3 is a detailed description and critique of the manpower cost elements of each of the models. Chapter 4 presents conclusions and policy implications based on a comparison of the model review presented here and the theoretical discussions of Volume II. Four appendices provide detailed descriptions and criticism of the models which extend beyond manpower concerns.

2.0 REVIEW OF COST MODELS

This chapter summarizes the results of a review of seven Navy cost models, including four level of repair models and three life cycle cost (LCC) models. The four level of repair models are taken from MIL-STD-1390B (Navy). These models are:

2. Naval Electronic Systems Command Equipments
3. Naval Sea Systems Command Ships Equipments
4. Naval Sea Systems Command Ordnance Equipments.

Two of the life cycle cost models were prepared for the Naval Material Command by the Naval Weapons Engineering Support Activity. They are:

1. Life Cycle Cost Guide for Equipment Analysis
2. Life Cycle Cost Guide for Major Weapon Systems.

All of the models listed above are general-purpose models provided by the Navy for use in a wide variety of programs. The final model reviewed, the SEAFIRE Life Cycle Cost Model, is a special-purpose LCC model provided by the Navy for use on a specific procurement called SEAFIRE. It is included as a typical example of cost models of this type.

2.1 The 1390B Level of Repair Models

The four level of repair models are published as Military Standard 1390B Level of Repair. They have been listed in the order of their usage (which is also the order in which they appear in the Standard). The Air and Electronics Systems Models are both fairly widely used, with the Air Model being the more widely applied of the two. Both models are available in computer program form. The Air program is written in SIMSCRIPT,

however, which means that there are very few contractor facilities which have the capability of running the program in-house, thus limiting its general utility in the design process. The Ships and Ordnance Equipments Models are less frequently used.

An important point to be made about the 1390B models is that, at the time of this writing, the *earliest* they have ever been used in the design process has been in the full-scale development phase. More often, however, they are not used until the production, or even deployment, phases of the WSAP.*

Are the models at all useful, or potentially so, for conducting tradeoffs? The models are large and complex, and thus difficult to use. If they are not implemented on computer programs it would require a great deal of effort to run through the models iteratively for tradeoff purposes. Because of lack of availability of SIMSCRIPT compilers at contractor facilities, it is difficult for the designers to get their "hands on" at least the Air model, limiting the utility of the model. This, coupled with the large input data requirements of the models, may explain the limited use of the 1390B models early in the design process.

The 1390B models ignore the largest manpower cost and one of the largest costs of any weapon system: operator wages and training costs. The rationale behind this omission is that the number and skill levels

*According to Mr. Paul Gross of the Naval Weapons Engineering Support Activity.

of operators is not a function of level of repair. This renders the models useless in conducting an important class of hardware versus manpower tradeoffs--hardware elegance versus operator skill levels and quantity. A second class of hardware manpower tradeoffs is hardware reliability versus maintenance personnel skill. The 1390B models include cost equations for maintenance personnel wages and training, which will be dealt with in detail in the next section of this chapter. Briefly, however, the models are still inadequate in this area for two reasons:

1. manpower costs are incorrectly calculated, leading to large underestimates of the actual costs of maintenance labor, and

2. the inputs and equations used are not such that it is possible to deal with important tradeoff issues such as equipment design versus maintenance skill levels and training requirements.

For these reasons the 1390B models are not useful for conducting hardware/ manpower trade-off analysis.

The 1390B models allocate costs to six major cost categories: inventory, support equipment, space, labor, training, and documentation. For the item being considered in the model, the cost in each category is calculated using different level of repair alternatives. The Electronics Model, for example, considers three alternatives: local repair, depot repair, and discard. The Ships Equipment Model, on the other hand, considers eight different LOR alternatives which include a variety of mixed repair postures.

The Air Systems Model is unique among the 1390B models reviewed in that it can simultaneously consider three levels of indenture for equipments: WRA (Weapon Replaceable Assembly), SRA (Shop Replaceable Assembly),

and sub-SRA. The computer program on which the Air Model is implemented includes a complex optimization routine which automatically chooses the least-cost mix of LOR postures for an item and all its sub-assemblies. The other models are single indenture models, which means they must be run for each of the MRU's (Minimum Replaceable Units) which make up an item.

Finally, our second criterion for evaluation of the models, are costs calculated correctly, has already been partially dealt with: manpower costs at least are not done correctly. There are other major and minor errors in the cost equations of the 1390B models. Detailed reviews of these equations are provided in the appendices of this volume.

2.2 Life Cycle Cost Guide for Equipment Analysis

The NAVMAT Life Cycle Cost Guide for Equipment Analysis (from now on referred to as the Equipment Model) was developed for the Cost Management Division of the Naval Weapons Engineering Support Activity (NWESA). The model inputs cost and technical data on an equipment to be procured by the Navy, and produces estimates of the total life cycle cost of that equipment.

The Equipment Model is one of the most widely used general purpose life cycle cost models.* It has been applied on many different projects, and at all phases of the design process. At the time of this writing, NWESA is attempting to have the Equipment Model promulgated as a military standard.

*According to Mr. Alpuan Atay of NWESA.

There are two major points to be made about the Equipment Model. First, the Equipment Model is designed to be a general-purpose model which can be adapted to a variety of equipments. Because of this generality, the standard Equipment Model is not appropriate for conducting hardware/manpower tradeoffs--as well as most other kinds of tradeoffs--since, with the exception of some maintenance-related costs, all the input variables to the model are direct throughputs; that is, they are subjected to no mathematical processing other than being summed to the total cost (after having been adjusted by a discount/inflation factor).* Altering one design factor will not, in most cases, affect related factors. As an example, the number of maintenance personnel to be trained is a direct input variable. Changes in equipment inventory size or equipment module failure rates will have no effect on this number.

The second point goes a long way in mitigating the first. The Equipment Model is designed to be flexible: the computer program on which the model is implemented enables the analyst to modify the standard Equipment Model to suit his specific project needs without making any program changes. Changes in the equation structure of the model can be made by submitting them as data to the program. This feature of the program, called the FLEX technique, may be applicable in producing an adaptation of the standard Equipment Model suitable for hardware/manpower tradeoffs. However, due to inherent limitations in the FLEX technique, specifically its inability

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* This definition of throughput includes calculations of the form (number of X) times (unit cost of X). Note also that suitability for general purpose was only achieved by the use of non-analytic methods.

to handle any logical flow processing, it might be necessary to make changes in the program code of the Equipment Model in order to adapt it for tradeoff analysis.

The mathematical structure of the standard Equipment Model is the following. Total life cycle costs are divided into three major cost elements: Research and Development, Investment, and Operating and Support. These cost elements are calculated as the sum of 61 basic cost equations which require as input 104 cost factors. Each cost equation is assigned to one of ten cost categories, one of six funding types, and can be adjusted by one of four types of inflation factor and one discount factor. Each cost equation is assigned a cost breakdown structure number which determines the position of the equation in the cost aggregation hierarchy. The cost of a cost element is the sum of all indentured cost elements below it. This requires that only those cost elements which do not have lower indentured cost elements need be described by equations; the model automatically takes care of cost aggregation. The Equipment Model calculates the cost of each equation by year for each year covered by the life cycle cost analysis. These costs are then adjusted as required by a discount/inflation factor.

A complete description of the structure of the Equipment Model plus a description of the FLEX technique and an example of its possible application in adapting the Equipment Model for hardware/manpower tradeoff analysis are provided in Appendix B.

Using our evaluation criteria, the following statements can be made about the Equipment Model. The model can be used early in the design

process. While the standard model is not useful for most tradeoff analyses due to its generalized form, the FLEX technique may be applied to adapt the model to this end. The Cost Breakdown Structure of the model is very complete and provides a good framework for building relationships between mutually dependent factors. Since most of the cost equations are simply throughputs of input data, the accuracy of the cost calculations only depends on the quality of the input data. Many of the input variables require considerable calculation external to the model in order to arrive at a reasonable estimation for their value; an example of an input variable of this type is the number of organizational and intermediate maintenance personnel to receive initial training. Changing such input variables from throughputs to mathematical expressions in which their values are calculated from other input data available to the model (in this case, for example, the mean time between failure and mean time to repair the equipment can be used to calculate the maintenance manpower requirement) is an example of one of the simplest and best uses of the FLEX technique. Other input variables to the model would be difficult if not impossible to estimate under any circumstances; an example would be contractor software development costs. Accurate values for such variables could only be input to the model after the fact.

2.3 Life Cycle Cost Guide for Major Weapons Systems

The Life Cycle Cost Guide for Major Weapons Systems (from now on referred to as the Major Systems Model), developed by the Naval Weapons Engineering Support Activity, is designed to produce estimates of the total

life cycle cost that may be attributed to a particular weapon system. The cost estimate obtained is intended for use in tradeoff analyses between competing weapon systems (or different major design variations of the same system), to determine whether the development of a weapon system should continue, or for a variety of similar purposes. The Major Systems Model is intended to be a general model which may be adapted to a variety of weapons systems such as aircraft and ships.

The Major Systems Model was developed very recently; the standard version of the model only became available to users early in 1978. The model has not, therefore, yet been used on any actual project.

The Major Systems Model is not intended by its authors to be a rigorous set of costing rules which must be followed to the letter. Rather, as its name suggests, it is intended to be a "guide" for the cost analyst and program manager (but *not* the system designer) which indicates the major cost factors to be considered in trying to meet various cost/performance/schedule goals for the system. Like the Equipment Model, the Major Systems Model is designed to be flexible: the computer program on which it is implemented includes the same FLEX technique options as does the Equipment Model.

As in the Equipment Model, nearly all of the input variables to the Major System Model are direct throughputs which are added to the estimated total life cycle cost after having been adjusted by a discount/inflation factor. Many of the input variables would have to be computed outside the model. An example is the cost of initial spares acquisition. This cost, one of the most complex formulations of any cost element in life

cycle cost (a full treatment of its estimation is included in the Appendix covering the 1390B models) is throughput in the Major Systems Model.

In reviewing the Major Systems Model, the following conclusions can be drawn. First, the model is not really a "model" in the sense that it performs any sort of analytical procedures for estimating the costs associated with a weapon system. Rather it is an elaborate accounting system and cost breakdown structure which tells the user what major costs he must consider, and offers the option of the FLEX technique to allow him to estimate those costs as he sees fit. In this capacity, the Major System Model does an excellent job. The cost breakdown structure is very complete and the documentation explaining the model and the use of the FLEX technique is clear and can be quickly grasped by the user. Therefore, the System Model is *potentially* useful in the design process as a tradeoff tool, but this potential could only be realized after considerable effort has been expended (hopefully within the FLEX methodology) to replace many of the broad, aggregate cost input factors with interrelated cost equations driven by independent inputs which do not require such extensive calculations external to the model.

In all the other models which we will review, manpower costs are computed in a few separate equations. Whether or not these costs are computed correctly, it is relatively easy to pull the manpower costs out of the model and compare them with other costs. In the Major Weapon System model, however, manpower costs are computed in different parts of the

model and are often buried in other cost factors. As a result, it is impossible to shred out manpower costs for the purposes of manpower-hardware tradeoffs. To do so would require extensive revisions of the model structure. A complete description of the structure of the Major Weapon System Model is provided in Appendix C.

2.4 The SEAFIRE Cost Model

The SEAFIRE Cost Model is a special-purpose model designed to estimate life cycle costs associated with the Electro-Optical Fire Control Subsystem (SEAFIRE) Program. It was developed by the Naval Surface Weapons Center, Dahlgren Laboratory, for the Naval Sea Systems Command. The SEAFIRE model is included in this report for the following reasons:

1. It is an excellent example of the type of special-purpose models provided for use by Navy Program Offices for contractors working on competitive design efforts.

2. It is intended to be used as a tradeoff analysis tool for the minimization of life cycle cost--in this case a source selection criterion.

The SEAFIRE model is written in FORTRAN IV for the CDC-6700 computer. Total costs are computed for each year of the estimated twenty-year life cycle of SEAFIRE. Life cycle costs are divided into three major time-phased cost categories: Engineering Development and Pilot Production, Full-Scale Production, and Operating and Support. The first two cost categories have no cost equations associated with them: what is provided is a set of arrays with dummy variables into which annual costs for sub-elements of these cost categories, as determined by the user, can be input to the model.

The Operating and Support section of the SEAFIRE cost model includes a complete set of cost equations. This section of the model operates at two levels of indenture: system and subsystem. Variables are input to the model at three levels. First, each subsystem, up to a maximum of eight subsystems, is characterized by various cost and technical parameters. Second, the system as a whole has associated with it system level inputs. Finally, the operating environment of the system is characterized by a series of default input parameters provided by the SEAFIRE Program Office.

The structure of the SEAFIRE model is such that it could be made useful for tradeoff analyses. It is programmed in a widely-used language and can provide extremely rapid turnaround on cost runs. The documentation associated with the program is sketchy, but the input formats of the computer model are simple to use. Unfortunately, the mathematical structure of the cost equations severely limits the models usefulness in conducting tradeoffs.

No guidance of any kind is provided as to what cost elements are involved in the RDT&E and Production phases of the system life cycle. The model, for reasons which will be explained in detail in the next section, is not useful for conducting hardware/manpower tradeoff studies. Finally, there are numerous conceptual and mathematical errors in the cost equations of the operating and support subroutine of the computer model. A detailed discussion of the SEAFIRE cost model is provided in Appendix D.

3.0 MANPOWER COSTING IN THE MODELS

Manpower costs in the models are estimated for three major cost categories: compensation, training, and other manpower costs. However, only the Major Weapon System Model allows the user to deal with other manpower costs including such elements as security, staff, administration, and support. In addition, only the Major Systems Model can deal simultaneously with manpower of different skill and pay grade levels. The price of its more fulsome coverage, however, is that the Major Weapons System Model offers no guidance for determining the values of the multiplicity of manpower-related input variables used in the model.

Operator wages and training are included only in the life cycle cost models. The 1390B LOR models exclude all operator costs due to their basic philosophy that costs which are not a function of LOR policy need not be included in LOR analyses.

Maintenance wages are computed in all the models using hourly wage rates and maintenance requirements. The requirement is based on the mean time between failure and mean time to repair of the item. As will be discussed later, this method understates maintenance labor costs.

All the models have severe deficiencies in the general area of maintenance training. The basic problem arises in estimating the number of maintenance personnel to be trained and the cost of that training. None of the models provides an accurate method of estimating these values.

3.1 Compensation

A generalized formula for the compensation costs of personnel associated with a system is the following:

$$\text{Wage Costs} = NB_n + \Sigma\, MB_m$$

where N is the number of operators, B_n is the operator billet cost, M is the number of maintenance technicians at a particular maintenance level, and B_m the billet cost for maintenance personnel. All the models recognize that operators and maintenance personnel constitute two completely separate classes of personnel, and that the problems encountered and methodologies used in determining their costs are different in several fundamental ways.

The summation of maintenance personnel costs indicates that there are different types of maintenance personnel at different repair sites (organizational, intermediate, and depot). Further, there are different types of maintenance actions, each contributing to the total maintenance requirement of a system. Finally, the total number of maintenance personnel depends on the failure rates and repair postures of the various subelements which make up the system--factors which have complicated interrelationships.

The single most striking difference between the methodologies for computing operator wage cost and maintenance wage cost is the simplicity of the estimation of the former and the complexity of the latter. The simple expression NB_n is the exact formulation used by the three life cycle cost models for calculating operator wage costs. The formulation in the level of repair models is even simpler: operator costs are completely omitted. The reason for this omission if twofold:

1. Operator costs are usually not allocable to a single assembly undergoing LOR analysis;
2. It is assumed that operator costs do not vary as a function of the repair postures of the elements which make up an equipment, and therefore need not be considered in a level of repair analysis.

Unfortunately, even if the reasoning is valid, the omission of operator costs renders the 1390B models useless for conducting an important class of hardware/manpower tradeoffs; namely, equipment design versus operator skill levels.

In calculating the cost of maintenance wages, three different types of labor are recognized: preventative maintenance and two classes of corrective maintenance. Preventative maintenance includes such activities as overhauls, scheduled tests, scheduled replacements, and so on. None of the 1390B models includes preventative maintenance in its cost calculations. All other models reviewed include this requirement. The first class of corrective maintenance labor, called "swap-out labor," is the labor required to fault isolate, remove, and replace a sub-element of an assembly. Regardless of the LOR policy of an element, swap-out labor must always occur. The second class of corrective maintenance labor, called repair labor, is the labor involved in repairing the failed element so it can be returned to ready-for-issue status. Where this labor occurs--if it occurs at all--depends on the LOR policy for the element.

The distinction between swap-out and repair labor leads to considerable confusion and several conceptual errors in the maintenance labor calculations of several of the models.* The Ordnance Model, for example, fails to account for swap-out labor in the cost of repair actions. This tends

* To compound the problem, throughout the 1390B models swap-out labor is referred to as "discard" labor because the amount of labor and training required for the two actions are identical (a discard action is simply a swap-out in which the failed element is not repaired).

to bias the user toward a repair alternative as opposed to discard. The Ship's Equipment Model and the SEAFIRE Model exclude *all* swap-out costs (which implies that the maintenance labor and training costs for a discard posture are zero). This is done deliberately in the Ships Model, "since these costs would be added equally to all LOR decision alternatives, and are therefore not a function of level of repair." This fallacious reasoning stems from the fact that the Ships Equipment Model is a single indenture level model. The multi-indentured Air Model correctly recognizes that swap-outs can occur at different levels of maintenance activity (with associated differences in cost) depending on the repair posture of the higher level assembly which contains the element. As opposed to the Ordnance Model, then, the Ships Equipment and SEAFIRE Models will tend to bias the user toward a discard posture in which labor costs are seemingly non-existent.

In all of the models other than the Major Systems Model (which inputs the number of maintenance personnel directly), the total wage cost for maintenance personnel is computed from the total number of direct maintenance actions of the three classes discussed above. A generalized formula for the total cost of maintenance labor as computed by the models is the following:

$$\begin{pmatrix}\text{cost of}\\ \text{maintenance}\\ \text{labor}\end{pmatrix} = \begin{pmatrix}\text{number of}\\ \text{maintenance}\\ \text{action}\end{pmatrix} \begin{pmatrix}\text{direct}\\ \text{manhours}\\ \text{per action}\end{pmatrix} \begin{pmatrix}\text{cost}\\ \text{per}\\ \text{manhour}\end{pmatrix}$$

where the number of maintenance actions is computed by dividing the equipment operating time by the mean time between action.

While at first glance it may seem that this formulation is different from the one presented at the beginning of this section, this is not really the case. The product of the first two factors yields the number of maintenance personnel; the third factor is their cost. The difference between the two formulations, therefore, is that in the first costs are expressed in terms of men, and in the second in terms of manhours.

Two points must be raised about this approach to maintenance manpower costing. First, the factor "direct maintenance manhours per action" should be replaced by "the average total number of maintenance manhours associated with a maintenance action of this type," which in general will be significantly greater than the mean time to repair of the item.* It is simply not correct to allocate only ten minutes of maintenance time to a repair (assuming an MTTR of ten minutes) if after the ten-minute remove and replace action the maintenance technician must (as is almost always the case) spend an additional hour's time in maintenance documentation, packaging the failed item to be shipped for repair (if it is so coded), and other administrative and overhead duties associated with the repair.

The second point which must be kept in mind is that the wage cost per maintenance manhour will only reflect the true cost to the Navy of providing manitenance labor if it is computed by dividing the annual billet

*While Mil. Std. 1390B does not use the variable MTTR, their definition of direct maintenance manpower per action converges to MTTR if only one repairman in involved (the normal situation), *viz*, "The number of man hours required to fault isolate to the item level and to replace the item." See page 2, Mil. Std. 1390B.

cost of maintenance personnel by the total number of hours per year that the technician is available for maintenance duty. This number will vary as a function of the operational environment in which the technician is working.

Even if these corrections were made, however, the maintenance costs calculated as described above would still not reflect the true cost to the Navy of the maintenance wages associated with an item, since they do not include such critical cost factors as whether the personnel are new or already assigned to the platform, training levels, utilization rates, and so on. These factors were discussed in Volume I of this report.

3.2 Training Costs

A general formula for the initial training costs associated with a system looks very similar to the formulation for compensation:

$$\text{Training Costs} = NT_n + \Sigma\, MT_m$$

where T_n and T_m are the costs of training operators and maintenance personnel, respectively. As was true for compensation costs, the two cases of operators and maintenance personnel lead to very different problems in the estimation of the costs of training.

A correct way to deal with the problem of determining the number of maintenance training billets and the length of the training course developed in Volume I, Chapter 3, is to build up these numbers from the maintenance

manpower and training requirements of each of the sub-elements of the system, to which would be added system level requirements.

Unfortunately, none of the models reviewed estimate training requirements in this manner. In *all* of the models, the cost of training is a simple input variable.* This is also true for the number of men to be trained, except in the Ordnance and Electronics Models, which calculate the number of maintenance men to be trained as follows:

$$\begin{pmatrix}\text{trained}\\ \text{men}\end{pmatrix} = \begin{pmatrix}\text{number of}\\ \text{maintenance}\\ \text{actions}\end{pmatrix} \begin{pmatrix}\text{manhours}\\ \text{per}\\ \text{action}\end{pmatrix} \div \begin{pmatrix}\text{available}\\ \text{manhours}\end{pmatrix}$$

This approach is a step in the right direction in determining the correct number of training billets. The Electronics Model takes a further step by rounding the value computed to the next higher integer for the entire deployed system to indicate that only whole men, not fractional parts of them, can be trained. A more appropriate application of this device, however, would have been to round up for each site: the difference in the number of billets to be trained can be substantial.

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* In the SEAFIRE model the situation is even worse. The input variable for training cost is a default parameter provided by the SEAFIRE Program Office, and thus is not subject to tradeoff analysis. What is more, the value provided is an average value for operator and maintenance training costs, which are not estimated separately. Potential tradeoffs that would affect the number of personnel to be trained will therefore be costed incorrectly.

4.0 CONCLUSIONS AND IMPLICATIONS FOR POLICY

A comparison of the theoretical concepts discussed in Volume II and reality, as revealed in this review, indicates a wide disparity--not just in practice, but even in the topics of concern. The conclusions discussed in the first part of this chapter are an attempt to interpret those disparities in a logical manner, identifying what are perceived to be the major problems documented. The second part of this chapter details the implications these conclusions bear for policy formulation. We stop short of stating formal policy recommendations since doing so falls outside the scope of our charter. Nonetheless, the drawing of policy implications should provide a reasonable starting place for policy makers interested in alleviating the problems discussed here.

4.1 Conclusions of Review

Five major conclusions are drawn below. Each of these includes a number of subsidiary concerns seen as part of the larger problem. The implication of this ordering of concerns is that solutions to the subsidiary problems would not, ultimately, have much impact on the major concerns. That is, problems of philosophical approach or sweeping policy can have a number of effects, spread through the WSAP. Attacking the effects is at best inefficient and at worst a counter-productive approach to solution: the major issues must be resolved sooner or later. When they are, the minor concerns tend to be swept along to consistent solutions.

1. *Manpower Costs are Always Understated.* For a variety of reasons, the models reviewed understated manpower costs to the point that no real manpower savings could even be measured in the process of weapon system acquisition. The only possible exceptions to this lack were the two cost Guides (Equipment and Major System) developed under the auspices of the Chief of Naval Material. Yet neither of these instruments are, in fact, models. Both are elaborate accounting structures with few analytical implications. The availability of the FLEX option, while promising, imposes so heavy a burden on the user and allows so much room for error, that it is unlikely the techniques will receive much use as models--nor would that necessarily be desirable.

The most important elements of this lack are in the failure of all models to recognize billet creation as a process distinct from incurring direct labor costs. Other elements include the failure to distinguish

between training and compensation billets, the all but uniform disregard for operator personnel costs and the persistent disregard for what we have called other manpower costs. The latter includes all indirect labor, command and administrative support costs, security clearance costs, and a number of others.

The principal outcome of understatement of labor costs is to reinforce a problem which the Navy should be moving forcefully to correct. The problem referred to is that the Navy's capital stock and management techniques are both geared to the relatively low labor costs which prevailed up to the last few years. Even if the factor price change were being properly measured at every level in the Navy, it is probably true that the infrastructure changes necessary to accommodate the change would be a long time in coming. The inability of cost models to correctly portray capital labor cost tradeoffs simply makes this necessary transition more difficult.

2. *Labor Type Tradeoffs are Impossible*. While capital labor tradeoff analysis is, at best, distorted by understatement of labor costs, labor *type* tradeoffs are not possible with the models reviewed. This lack is especially puzzling because of the simplicity of accommodating such tradeoffs and the demonstrably large gains available (in many cases) by considering other forms of labor. The driving consideration here is the same as that evidenced by the first conclusion: factor prices have changed and the Navy must be apprised of the difference if it is to allocate its resources efficiently.

None of the model structures investigated were capable of accommodating different patterns of usage for military and other types of labor. While not surprising in the Guides (because they are accounting structures only), this lack in the level of repair models and the SEAFIRE model is disturbing. The operating and support era of an equipment's life cycle is the time when such tradeoffs are possible. In order to reflect the potential savings, additional support policy options could have been included in each of the level of repair models which reflected, for example, the use of a contractor operated depot (COD). This, in the terms of Volume 2, is a tradeoff between military labor and value added labor.*

Comparisons between military and general schedule employees, and between either of these and civil service personnel are more difficult to carry out. There are two reasons. First, the patterns of work activity and therefore the process modeling involved are quite different between military and civilian personnel. Second, there are significant policy barriers to civilianization which influence the model builder's ability to capture alternatives in a rigorous manner. However, in weapon system acquisition, both of these alternatives probably have smaller cost saving implications than the use of value added labor.

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* The authors of this report have produced a number of level of repair models for private firms as well as military agencies. It has been standard practice to include a COD option in these models. Significantly, this option has *always* proved least cost among the policy options investigated.

3. *There are no Linked and Graded Model Systems.* This is not surprising since the idea is new to the Department of Defense. Each of the models reviewed was developed with a particular period of the WSAP in mind, and a particular analytic problem.* The only exceptions are, again, the cost Guides. However, any grading of these models is left to the user. Furthermore, the emphasis placed on budget categories makes the models far more relevant to the later stages of the WSAP than the early stages.

The problem goes deeper than this, however. The SEAFIRE model, intended for use in the engineering development phase, is represented as an example of program office models. While the practice of developing such models is widespread in the other military departments, this is the only example we have been able to find in the Navy. There are undoubtedly others, but not many. Furthermore, we were unable to find *any* gross parametric models suitable to the development of specifications for new systems on the basis of operational requirements. Again, there may be some examples in the Navy, but not many.

What emerges, then, is an emphasis on the later stages of the WSAP, rather than the critical early stages. None of the models reviewed shows any potential for being a useful design/cost trade-off tool (for all types of trade-offs, not merely those between hardware and manpower) during the early stages of design, where 90% of ultimate life cycle costs are determined.

*This is a polite assumption. In fact, there seems to have been no recognition of the fact that data availability changes widely over the WSAP - and that it is quite limited in the earliest, most crucial stages.

4. *General Purpose Models are Not Cost Effective.* There is an extensive literature in computer science which argues the pros and cons of general purpose software. The models reviewed which were intended as general purpose tools are eloquent examples of the problems associated with general purpose software. Both the cost Guides and the 1390B models are excessively complex as a consequence. The documentation provided for the 1390B models is lengthy and difficult to understand even in a general context. The documentation for the Guides is good; but these models are still far from simple to understand fully. If an individual wishes to actually use one of the models for a particular cost analysis problem, the complexity multiplies.

The usual defense for such general purpose models is that everything is there--all the user has to do is figure out what to ignore. But that is a tall order for two reasons. First, deleting elements from a cost structure is a technical problem which requires that the analyst understand the structure completely. He may wish to delete most of the content of a particular element, but not all. Some structures simply don't make this possible--or require an excessive amount of external computation to overcome the internal workings of the model.

The second reason has to do with the reluctance of a program officer to modify standard sources. Because of the review cycles he faces and his own lack of cost expertise, the program manager is concerned to justify any departure from standard practice. Even if the adjustment of special purpose models is relatively easy, the cost of documenting and justifying

those changes--both in time and funds--tends to dissuade him.

Recently, some justification for general purpose models has been generated by the idea that the model can be modified to suit a particular procurement. This includes modifying the mathematical structure as well and the program software. The Air Force claims some success with its Logistics Support Cost Model (LSC), promulgated by the Acquisition Logistics Division of AFLC, Wright-Patterson Air Force Base. To make the program feasible, ALD has found it necessary to staff offices at each of the major commodity commands at which reside specialists who consult with system program offices on modifications to the model. It is as yet unclear whether the benefits of this program outweigh its rather heavy costs.

The Navy's version of that example is demonstrated by the SEAFIRE model. Here, an informal process (apparently) occurred in which cost analysts at Dahlgren simply tried to draw the most useful parts of the 1390B models together in a tailored version. Their success, as reported above and in Appendix D, was mixed.

5. *Distinctions in Model Types are Counter Productive.* This conclusion does not follow strictly from topics treated explicitly in the review. Nonetheless, it effects all of the models and leads to significant costs of acquisition which could be avoided. The problem alluded to is the spurious distinction made between several types of models such as life cycle cost models, level of repair models, and operating and support cost models. The distinctions are not only misleading (since all are or should be the same), but has a counter productive effect on the WSAP.

The problem stems from functional division of responsibilities for what are known as "specialist" disciplines in the procuring commands. These disciplines include such things as supply support, life cycle cost, maintenance policy, test equipment, reliability and maintainability and a number of others. While it is certainly true that these amount to distinct concerns, it is also true that all of them are interwoven rather tightly. The *lingua franca* among them is cost. Yet each group of specialists has created its own program requirements and frequently, its own set of cost models. The disparity of methods leads to inconsistent planning and cost estimates. The independent development of program requirements leads to redundant and conflicting data sets. It is not uncommon, for example, to find reliability estimates generated by as many as five different groups at a contractor's facility.

In the models reviewed here, we have seen three distinct sets of goals addressed by different models. The 1390B models are intended for level of repair analysis (a maintenance planning concern), the cost Guides were developed primarily for budget estimation and the SEAFIRE model was intended as a combination of budget estimator and design tool. The names of the different programs which utilize one form of cost model or another are illuminating: level of repair, life cycle cost, design-to-cost, design-to-unit-production-cost, logistics support analysis and reliability, maintainability and availability. In the present way of doing things, several generalized models, each only applicable to a strictly limited area of design/cost analysis, are used. The same end would be better met by providing a single model (or model system) specifically tailored to the needs

of each individual project, which would encompass all of the design elements previously dealt with in the separate models.* More to the point, the cost to the Navy of buying the information produced by these program elements would be reduced significantly and inconsistancies eliminated if the same cost models were used.** Finally, the process by which a conceptual design against an operational requirement was translated into concrete hardware design would benefit enormously from the ability to jointly address all such concerns through the same medium.

*This is not in conflict with the objections raised in Volume II, Chapter 4, concerning parametric cost models. The costs involved in adapting parametric models to different projects were shown to be extremely high.

**For example, in one contractor facility the SEAFIRE model is being used to conduct LCC analyses while the 1390B Ordnance model is being used simultaneously to conduct LOR analysis. Some to considerable difficulty was reported in adapting the computer programs of the two models to run on the contractor's own computer facility. In addition, these models have many inconsistencies in their cost formulations (even though the former is, to some extent, an adaptation of the latter).

4.2 Policy Implications

Four areas are discussed below in which the policy implications flowing from the conclusions can be stated with some clarity. There are undoubtedly other implications that could be drawn from the discussion, but those are left to the reader. The areas discussed do not match one-for-one with the conclusions stated above. Instead, they represent what seem to be separable areas of concern which could be addressed independently and lead to useful results. We should emphasize again that these do not amount to policy *recommendations*. To go that next step would require a considerable effort to understand the cost of implementation. While all the changes indicated appear to be possible, some may be so costly as to be infeasible in practice.

Indirect Labor Cost

First, it appears reasonable to develop methods for handling indirect labor cost linkages. To do so would require a view of Naval manpower which distinguished between the suppliers of final services and those of intermediate services. Final services might be the operation and maintenance of combat systems while intermediate services are all those forms of indirect labor, the necessity for which is created by the size and composition of the final labor force. By formalizing a dependence structure of this sort in cost models used for the acquisition of equipments and subsystems, the cost of those entities would not only be better estimated, but planning information would begin to become available at a much earlier stage in the WSAP.

Labor Type Comparisons

The second area of concern is the ability to cost alternate forms of labor. While there are currently efforts underway to develop an analog of the Billet Cost Model for civil service employees, modeling techniques would have to be introduced to allow such comparisons to be made with regard to hardware acquisition. By introducing such questions as the ability to hire skills rather than develop them, this innovation would tread heavily on areas of policy which have not yet been fully resolved. Therefore, a pre-requisite to such costing (as a general requirement in the WSAP) would be the development of consistent policy guidelines concerning civilianization. As mentioned above, the purchase of civilian labor through value added to hardware poses no special policy problem except in the areas of depot maintenance and supply support.

Cost Method Standardization

A third area of policy concern is related exclusively to the last conclusion developed above. This is the need to develop policy, organization, managerial procedure and contracting practice changes which recognize the areas of similarity between various forms of analysis such as level of repair and life cycle cost. The separation of these concerns is only appropriate to the notion of sequential design--a practice specifically rejected by the philosophy of the HARDMAN effort. The sequence has always been to design an equipment first, cost it next, and plan its support last. The HARDMAN philosophy is that these activities, tc exploit opportunities to lower life cycle cost, must be simultaneous and iterative

rather than sequential. Unfortunately, the costs necessary to promulgate so sweeping a change in the WSAP are enormous. While we know that this is true, we have no good way to understand what they would be; a real barrier to initiating institutional change.

Policy Guidance

The last policy area is one which, for the most part, has already been officially addressed by the present study. This is the development of guidelines for the introduction of manpower costs to models during the WSAP (Volume I). These methodological guidelines provide cost analysts and program managers with the technical information needed to create a series of linked and graded models appropriate to the growing level of knowledge provided by their programs. There are two problems which remain, however. First is the simple fact that those guidelines are the product of a study and nothing more. Ultimately, they must be backed by directives, standards, and an educational process which will see them into widespread use.

The second problem is that models are not enough. Program offices understand that they are in a situation of controlled conflict with competitors seeking hardware contracts. They do not, however, generally understand the ways in which cost models can be used to foster competition and as program control devices after a contractor has been selected. Another set of guidelines, detailing the uses of cost models and the ways in which those uses can best be implemented is also required.

The general conclusion of this review is that Navy cost methods are inadequate for manpower cost analysis as part of the weapon system acquisition process. Even so, significant institutional and policy changes have occurred in the Navy over the past decade which make it possible to correct most of the deficiencies noted. Even though some of the changes indicated might be costly in an absolute sense, the potential for savings--in manpower and material and in the present and future--imply a very high rate of return.

APPENDICES

A: 1390B MODELS

B: EQUIPMENT MODEL

C: MAJOR WEAPON SYSTEM MODEL

D: SEAFIRE MODEL

APPENDICES

The appendices which follow are individual reviews of the seven models. Each review covers the entire model, attempting to indicate *all* of the most important problems, rather than concentrating solely on manpower cost estimation. The reason for this orientation is the concern for hardware/manpower tradeoff analysis which implies the need for adequate coverage and method applied to both. While the reader may be most concerned and therefore most familiar with manpower cost problems, it is instructive to see how poorly (in general) the estimation of other cost elements is carried out.

While not necessary, the reader will find that Section 2 of the main report is a valuable preface to the detail of the appendices.

APPENDIX A: 1390B MODELS

A.1 THE MILITARY STANDARD LEVEL OF REPAIR (MIL-STD-1390B(NAVY))

This section consists of a general introduction to the structure of the cost models which make up the Military Standard 1390B Level of Repair Manual. Four models from Mil-Std 1390B are covered in this review:

1. Naval Air Systems Command Equipments (AIR)
2. Naval Electronic Systems Command Equipments (ELEX)
3. Naval Sea Systems Command Ships Equipments (SHIPS)
4. Naval Sea Systems Command Ordnance Equipments (ORD).

The LOR models compute the support cost of an assembly as a function of its support posture, which states at what level maintenance activity (also called level of repair) the assembly is to be repaired. There are three levels of repair: local, intermediate, and depot. In addition there is the discard alternative.

The possible LOR alternatives of an assembly at each level are as follows:

Local:

1. Discard
2. Send to intermediate level
3. Send to depot level
4. Repair, discard if beyond capability of maintenance (BCM)
5. Repair, send to intermediate level if BCM
6. Repair, send to depot if BCM

Intermediate:

1. Discard*
2. Send to depot*
3. Repair, discard if BCM
4. Repair, send to depot if BCM

Depot:

1. Discard*
2. Repair, scrap and/or salvage if BCM

The alternatives for each level combine into eighteen possible LOR alternatives for a given item. Figure A-1 shows all the possible repair paths of an assembly. Of these, eighteen alternatives, only eight can be considered LOR *policies* in the sense that the item goes through a planned and reasonable repair route. These eight LOR policies are presented in Table A-1.

None of the models includes a consideration of all of the possible LOR policies. The policies which the models do include are the following:

AIR: four alternatives - 1, 2, 4, 7

ELEX: three alternatives - 1, 2, 4

ORD: four alternatives - 1, 2, 4, 5

SHIPS: eight alternatives - 1-7, and instead of policy number 8 SHIPS has a posture in which items replaced at the local level are sent to the depot for salvage

All four models allocate cost to six major categories, as shown in Table A-2. A brief discussion of each of the cost categories is presented in the following sections.

* An invalid alternative (for example, it makes no sense to send an item to the intermediate level only for it to be automatically discarded.)

Figure A-1. LOR Alternatives

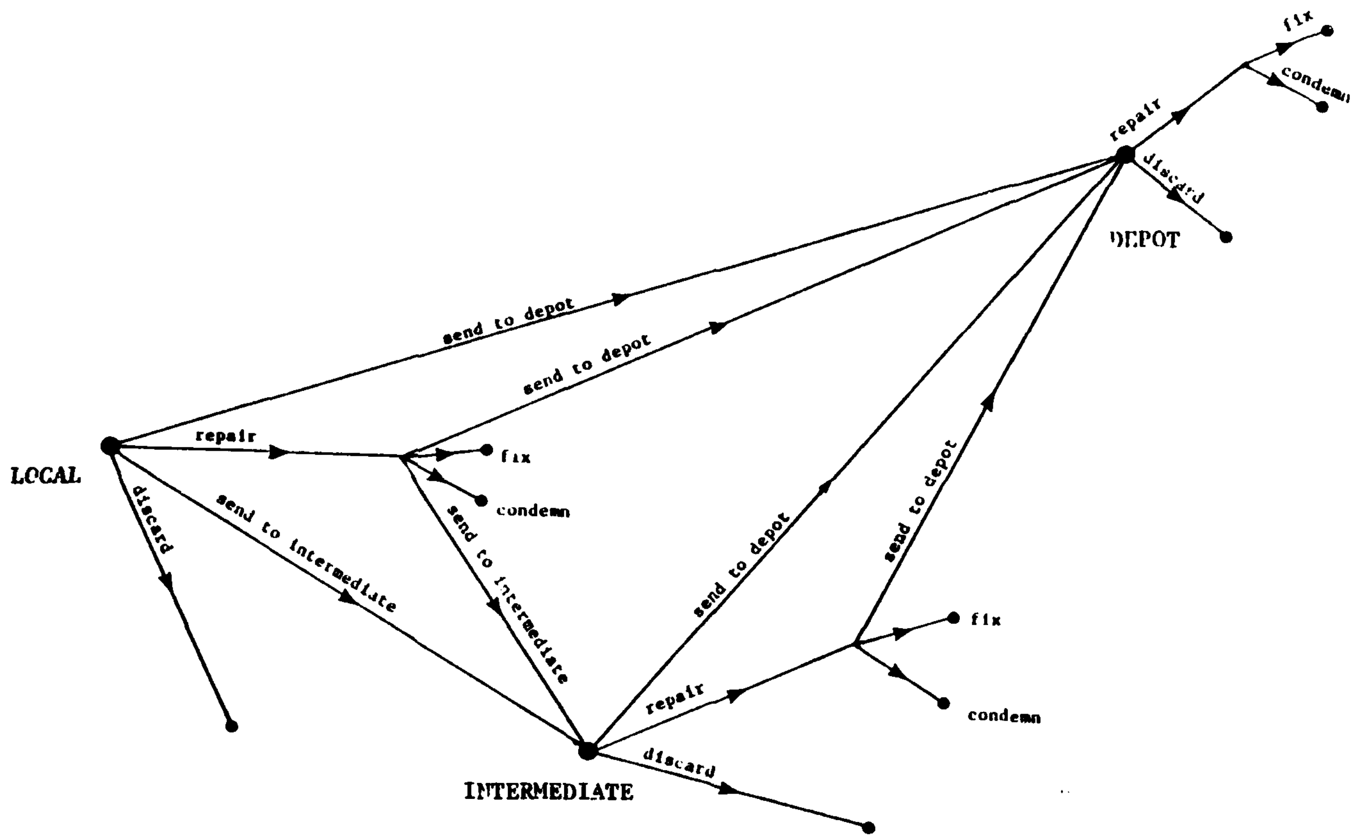

Table A-1. Level of Repair Policies

Policy	Local	Intermediate	Depot
1	Discard	No action	No action
2	Send to intermediate	Repair, discard if BCM	No action
3	Send to intermediate	Repair, send to depot if BCM	Repair, salvage if BCM
4	Send to depot	No action	Repair, salvage if BCM
5	Repair, discard if BCM	No action	No action
6	Repair, send to intermediate if BCM	Repair, discard if BCM	No action
7	Repair, send to intermediate if BCM	Repair, send to depot if BCM	Repair, salvage if BCM
8	Repair, send to depot if BCM	No action	Repair, salvage if BCM

Table A-2. Cost Categories in the 1390B Models

1. Inventory
    1.1 Inventory administration
    1.2 Spares inventory
        1.2.1 On-site quantity
        1.2.2 System pipeline stock
        1.2.3 Scrap replenishment quantity
    1.3 Repair material
    1.4 Transportation
2. Support Equipment
3. Space
    3.1 Inventory
    3.2 Support Equipment
    3.3 Repair work
4. Labor
5. Training
6. Documentation

1. Inventory

1.1 Inventory Administration Cost

All four models calculate inventory administration costs for two cases: discard and repair. It is calculated as the cost of item entry, which is a one-time cost, plus the costs of local management and retention of the item in the Navy Stock Number (NSN) system, which are annually recurring costs.

1.2 Spares Inventory

Spares inventory consists of three separate inventory quantities: the on-site quantity (the quantity stocked at the operational site to allow for immediate replacement of failed items); the system stock (the quantity used to replace items while they are in the maintenance pipeline); and the replenishment quantity (replaces items permanently lost to the system because they have been lost or scrapped). The on-site and system stock quantities are purchased at the beginning of the system's deployment, and are kept at a constant level throughout the system life cycle. The replenishment quantity, as modeled in the 1390B, is also purchased at the beginning of the deployment period, but, unlike the other two quantities, is constantly depleted throughout the life cycle and should be used up at its end.

The sizes of the spares inventory quantities depend on the failure rate of the assembly which is undergoing LOR analysis. The first step in all four models in determining the spares inventory quantities, therefore, is to determine the predicted number of failures of the assembly per site. The general equation used for this is the following:

$$F = N * H/(MTBF * K),$$

where N is the number of assemblies, H is the annual number of operating hours per site, MTBF is the mean time between failures of the assembly, and K is a reliability improvement/degradation factor.

ELEX, SHIPS, and ORD define F as the "annual number of replacements per site." AIR defines F as the "annual number of real failures per site" (which is what it actually is), and then defines D as the "annual number of items for disposition per site" and sets D equal to (F + false removals - false removals detected as such).

1.2.1 On-Site Quantity

The on-site quantity is the number of spare parts which must be stocked at the operational site to allow for immediate replacement of failed items. This quantity is computed from the expected number of failures of the item during a period of time, t. The number can easily be derived from F, computed above. For ELEX, SHIPS, and ORD, t is set equal to one quarter and the on-site quantity is called the allowance quantity. For AIR the on-site quantity is divided into two parts: the rotatable pool (for on-site repairs) and the attrition quantity (for items sent to a higher level of maintenance for repair). For the rotatable pool, t is set equal to the local repair cycle time; for the attrition quantity, t is set equal to the required days of stock at the local level.

The general idea behind the computational routine for on-site quantity in each of the models is to buy a quantity of spares equal to the expected number of failures during the time period t plus an additional, buffer stock.

The buffer stock is purchased to provide a 95 percent confidence level against stock-out at the operational site.* The calculation is based on the well-established finding that equipment failures follow a Poisson arrival distribution whose mean and variance are equal to the expected number of failures. Under certain conditions, the normal distribution can be used to approximate the Poisson, simplifying the computation:

$$\text{On-site quantity} = I(F_t + 1.645 \sqrt{F_t})$$

where F_t is the expected number of failures of the assembly during a time period t, and I(x) is an operator which rounds the value of x to the next higher integer.

The formula is not used in exactly this form in any of the models. Similar formulas are used, none of which computes the size of the on-site quantity correctly. A comparison of the number of spares which is purchased for the on-site quantity for each model is given in Table A-3. Note that when the demand is less than 10, all models consistently buy fewer spares than required for a 95 percent confidence level based on a Poisson arrival distribution, but that when the demand is greater than 10 all the models (except AIR) buy far more spares than required. Note

* If no buffer stock were purchased, the confidence level against stock-out would be 50 percent, since one-half of the times there would be more than the expected number of failures during a demand period.

Table A-3. On-Site Quantities and *Confidence Levels* Achieved as a Function of Demand

Demand	On-Site Quantity									
	SHIPS		ORD, ELEX		AIR		Normal Approx.		Poisson 95%	
.2	1	*98*	0	*82*	1	*98*	1	*98*	1	*98*
.3	1	*96*	1	*96*	1	*96*	2	*99*	1	*96*
.4	1	*94*	1	*94*	1	*94*	2	*99*	2	*99*
.5	1	*91*	1	*91*	1	*91*	2	*99*	2	*99*
.6	1	*88*	1	*88*	2	*88*	2	*98*	2	*98*
.7	1	*84*	2	*97*	2	*97*	3	*99*	2	*97*
.8	1	*81*	2	*95*	2	*95*	3	*99*	2	*95*
.9	1	*77*	2	*94*	2	*94*	3	*99*	3	*99*
1.0	2	*92*	2	*92*	2	*92*	3	*98*	3	*98*
2.0	4	*95*	4	*95*	3	*86*	5	*98*	5	*98*
3.0	5	*92*	5	*92*	5	*92*	6	*97*	6	*97*
4.0	7	*95*	7	*95*	5	*79*	8	*98*	8	*98*
5.0	8	*93*	8	*93*	6	*76*	9	*97*	9	*97*
6.0	9	*92*	10	*96*	7	*74*	11	*98*	10	*96*
7.0	10	*90*	11	*95*	8	*73*	12	*97*	12	*97*
8.0	12	*94*	12	*94*	9	*72*	13	*97*	13	*97*
9.0	13	*93*	13	*93*	10	*71*	14	*96*	14	*96*
10.0	14	*92*	15	*95*	11	*70*	16	*97*	15	*95*
11.0	24	*99.9*	24	*99.9*	12	*69*	17	*97*	17	*97*
15.0	33	*99.9*	33	*99.9*	16	*66*	22	*97*	22	*97*
20.0	43	*99.9*	43	*99.9*	21	*64*	28	*97*	28	*97*
50.0	106	*99.9*	85	*99.9*	51	*59*	62	*95*	62	*95*
100.0	207	*99.9*	160	*99*	101	*54*	117	*95*	117	*95*

also that the normal approximation to the Poisson is perfectly adequate over the indicated range.*

1.2.2 System Pipeline Stock

System stock is the quantity of spares on hand to replace items while they are in the maintenance pipeline, which means they are either in the process of being repaired, or they have been scrapped and a replacement item is being procured. These two quantities are computed as follows:

$$\begin{pmatrix}\text{System}\\ \text{Pipeline}\\ \text{Stock}\end{pmatrix} = \begin{pmatrix}\text{Annual \#}\\ \text{of Items}\\ \text{Scrapped}\end{pmatrix} \left[\begin{pmatrix}\text{Procure-}\\ \text{ment Lead}\\ \text{Time}\end{pmatrix} + \begin{pmatrix}\text{Safety}\\ \text{Level}\end{pmatrix}\right] + \begin{pmatrix}\text{Annual \#}\\ \text{of Items}\\ \text{Repaired}\end{pmatrix} \begin{pmatrix}\text{Repair}\\ \text{Cycle}\\ \text{Time}\end{pmatrix}$$

The safety level is an input variable in AIR and ORD, and is set at 10.5 weeks for ELEX and SHIP. The repair cycle time is input for AIR and SHIP, set at one-quarter for ELEX, and set at one year for ORD.

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* Comments on the "correctness" or "adequacy" of these formulations must be understood in the context of what constitutes normal practice. In fact, *all* formulations which compute spares requirements to a confidence specification independently are both incorrect and inconsistent with Navy spares procurement practice. To see this, note that a confidence level of 95 percent for each of five elements comprising a system (where a system failure is defined as a failure in any of the elements) yields a system confidence level of $.95^5$ or 77 percent. Unfortunately, there are very appreciable computational problems in sparing to a *system* confidence level rather than a part or element confidence level. The only models which do so correctly are either pure stockage models or adaptations integrated with life cycle cost models. Simplified approximations of the correct method are, of course, possible.

1.2.3 Scrap Replenishment Quantity

Assemblies are permanently lost to the system when they are scrapped or lost in the process of transportation and repair. These items must be replaced throughout the system life cycle. ELEX and ORD take into account the number of items lost due to pipeline leakages, while AIR and SHIPS do not. SHIPS and ORD take into account the economic return of salvage (computed as a negative cost), while AIR and ELEX do not.

1.3 Repair Material

The repair material cost is the cost of materials (wire, piece-parts, etc.) which are utilized to repair failed items. It is computed as the product of the total number of repairs of an item over the system life cycle, and the average cost of a repair part, which is computed as a fraction of the item unit cost.

1.4 Transportation

Transportation costs occur when items are shipped for repair or replacement. Transportation costs for the discard posture are one-way costs from depot to organizational levels. Repair transportation costs are two-way costs. The general computational routine is to compute the number of assemblies shipped and multiply this by a transportation cost factor, which is determined from cost estimating relationships (CER's) based on weight and size but not distance.

2. Support Equipment

The cost of support equipment is computed as the sum of support equipment acquisition cost, which is a one-time cost, and the annual maintenance of support equipment cost, which is a recurring cost and is computed as a fraction of the initial purchase cost of the support equipment.

3. Space

Space costs are computed as the sum of the cost of space for inventory, support equipment, and repair work. The factors involved in the computation are number of items, the size of the items, and the cost of space.

Incremental space costs on-board ship have the same problem associated with them as the incremental wage costs of labor, which was discussed in the body of the report. If the space is already available on a ship, then the marginal cost of utilizing that space is simply an opportunity cost. If the space is not available, then ships structural modifications, at enormous costs, would have to be undertaken. The latter almost never occurs, but if it does occur, it certainly wouldn't be costed correctly using the equations provided in the 1390B models.

4. Labor

The cost of labor is computed only for direct maintenance actions on the item itself. A general form of computation is as follows:

(cost of labor) = (number of maintenance actions)
x (manhours per maintenance action)
x (cost per maintenance manhour).

The different models go to various levels of detail as to the number of repair or discard actions per site, the number of manhours per repair or discard action, and the price of labor per site as a function of LOR policy. The level of detail of the labor calculations is shown in Table A-4.

The wage cost of system operators is not included in the models.

The labor cost for fault isolation and replacement is not considered in SHIPS, "since it would be added equally to all decision alternatives and therefore is not a function of level of repair." The rationale behind this is that the same number of items will have to be removed and replaced regardless of the repair posture. This implies, incidently, that the labor cost for discard in the SHIPS model posture is zero. This approach is not correct, for while it may be true that the same number of items will fail and have to be replaced regardless of the repair posture, it is not true that the cost of doing so does not depend on the LOR posture. Removing an item at a depot, for example, is more expensive than doing so at the organizational level. Even if this were not the case, deletion of the common cost distorts the relative cost of different postures, and can cause an incorrect selection of LOR by incorrectly balancing some other element of cost.

5. Training

The training cost is computed as the product of the number of men trained and the cost of training. The number of men to be trained is an input variable for AIR and SHIPS (no indication is given as to how this

Table A-4. Level of Detail for Maintenance Wage Calculations in the 1390B Models

Quantity	Distinctions AIR	ELEC	SHIPS	ORD
Cost of Labor	Discard; Local Repair; Intermediate Repair a) higher assembly local repair b) higher assembly intermediate repair; Depot Repair a) higher assembly local repair b) higher assembly intermediate repair c) higher assembly depot repair	Discard Repair	Repair only	Discard; Repair
Number of Maintenance Manhours	Repair a) CV b) NAS c) Intermediate d) Depot; Discard a) CV b) NAS c) intermediate d) depot	Discard; Repair	Repair only a) local b) inter-mediate c) depot	Discard; Repair
Number of Maintenance Actions	Discards and Repairs at CV, NAS, Inter-mediate, Depot	Number of Replacements	Number of repairs at loc, int, depot	Number of replace-ments
Labor Rate	CV, NAS; Depot	Naval; Civilian	Naval; Civilian	Naval; Civilian

number is to be determined).* ORD and ELEX compute the number of men to be trained as follows:

(number of trained men) = (number of maintenance actions per year) x (manhours per actions)/(available manhour per year).

SHIPS does not consider the cost of training to fault isolate and replace failed items, which implies that the training cost for the discard posture is zero.

6. Documentation

Documentation costs are either throughputs or are computed as a percentage of item production costs, neither of which adequately reflects the cost differences associated with level of repair.

Although the four models reviewed all come under the general aegis of the Military Standard 1390B and are all essentially similar in structure, there are many differences and inconsistencies between the models. One of the most striking of these inconsistencies is the use of a discount/inflation factor. SHIPS and ORD have neither factor; AIR includes a discount rate, but no inflation factor; only ELEX includes both factors. Some of the other differences between the models are summarized in Table A-5.

* SHIPS requires as input the number of men to be trained at each maintenance level (local, intermediate, depot) even though these numbers should vary as a function of LOR posture.

Table A-5. Some Key Differences Between the 1390B Models

Variable	AIR	ELEX	SHIPS	ORD
Beyond Capability of Maintenance Rate	x		x	
Repair Cycle Time	x		x	
False Removal Rate	x			
Manhours per Discard	x	x		x
Safety Level	x			x
Discount Rate	x	x		
Inflation Rate		x		
Technical Override Requirement		x	x	x
Field Survival Rate		x	x	x
Minimum Replacement Unit			x	x
Return on Salvage Factor			x	x
Field Supply Administration Cost	x	x		x

(An "x" indicates the model makes use of the cost factor.)

A.2 NAVAL AIR SYSTEMS COMMAND EQUIPMENT MODEL

The Naval Air Systems Command Equipment Model (from now on referred to as AIR), is a mathematical procedure for determining if and where avionics components should be repaired in order to minimize their expected life cycle support costs. This section of the appendix does not consist of an exhaustive review of AIR. Instead, we will discuss only those elements of AIR which differ from the generalized structure of the 1390B models presented in the preceding section.

AIR is the most commonly used of the 1390B models reviewed. Unlike the others, AIR considers three levels of indenture in an equipment part's hierarchy: WRA (Weapon Replaceable Assembly); SRA (Shop Replaceable Assembly); and sub-SRA. AIR is fully implemented on a computer program written in SIMSCRIPT. The program contains a sophisticated optimization routine for choosing the least-cost mix of LOR postures for all the WRA's, SRA, and sub-SRA's contained in an equipment.

At each level of indenture, there are four alternative LOR postures available. These alternatives are the following:

1. Intermediate repair (this occurs at operational sites, which are carriers and Naval Air Stations (NAS); the posture is the equivalent of local repair in the other models);
2. Prime-Intermediate Repair (this occurs at a PIMA [Prime-Intermediate Maintenance Activity], which is an NAS with additional repair facilities; this posture is the equivalent of intermediate repair in the other models);
3. Depot repair;
4. Discard.

AIR makes use of two major assumptions when assigning an LOR code to an assembly. The first assumption is that the LOR code assigned to a WRA does not depend on which of its SRA's failed (similarly, the LOR code for the SRA does not depend on which of its sub-SRA's failed). This simplifying assumption makes it possible to assign a unique LOR posture to an assembly. The second assumption made is that items can only be shipped to a level of repair higher than that for which its higher assembly is coded. In other words, if a WRA is coded Prime-Intermediate repair, none of its SRA's can be coded Intermediate repair.

Using these two assumptions, there are sixteen possible combinations of LOR codes for each sub-SRA. These alternatives are reproduced in Figure A-2.

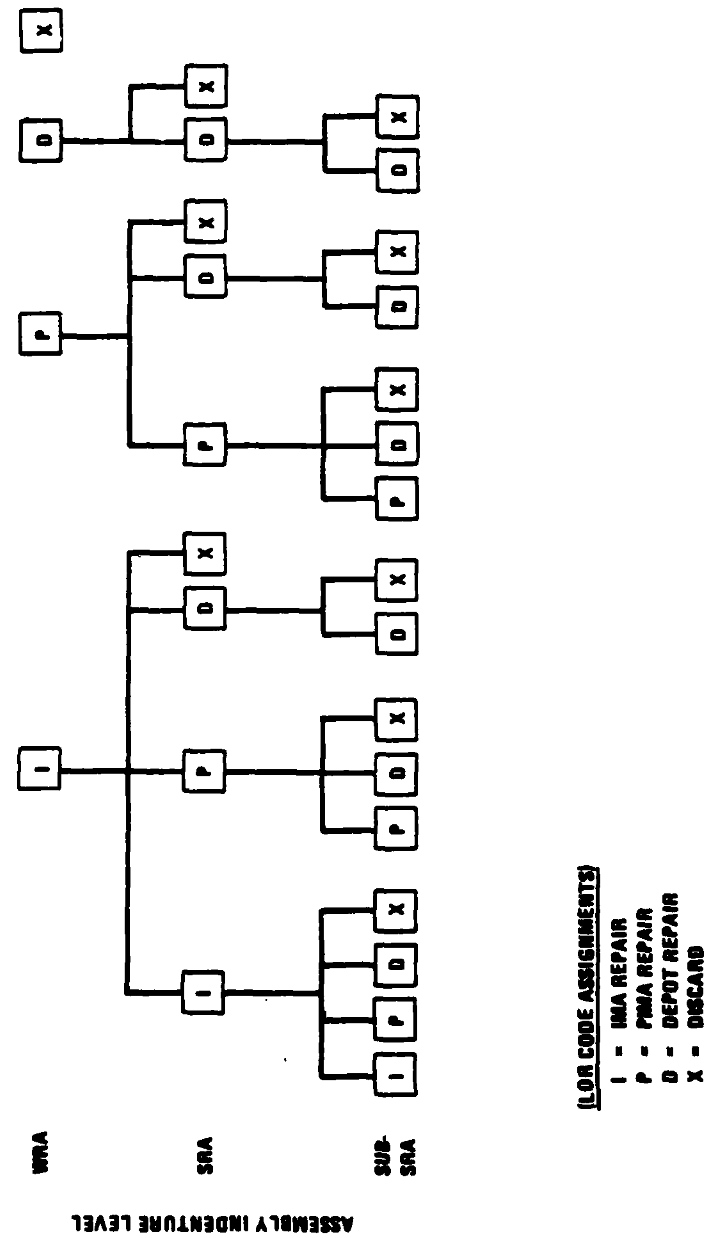
Spares Inventory in AIR

AIR is the only one of the four 1390B models reviewed which makes a distinction in its equation structure for spares inventory between the discard and repair postures.

For the discard posture, the entire spares inventory is included in a single stock quantity, called the discard inventory, which is equal to the anticipated number of removals during a year (the value which we called D, the number of items for disposition, in the previous section). There is no explicitly calculated on-site quantity or buffer stock computed for the discard posture.

For the repair postures, AIR makes yet another distinction in the spares inventory calculations not made in the other 1390B models. The

Figure A-2. LOR Alternatives in the AIR Systems Model

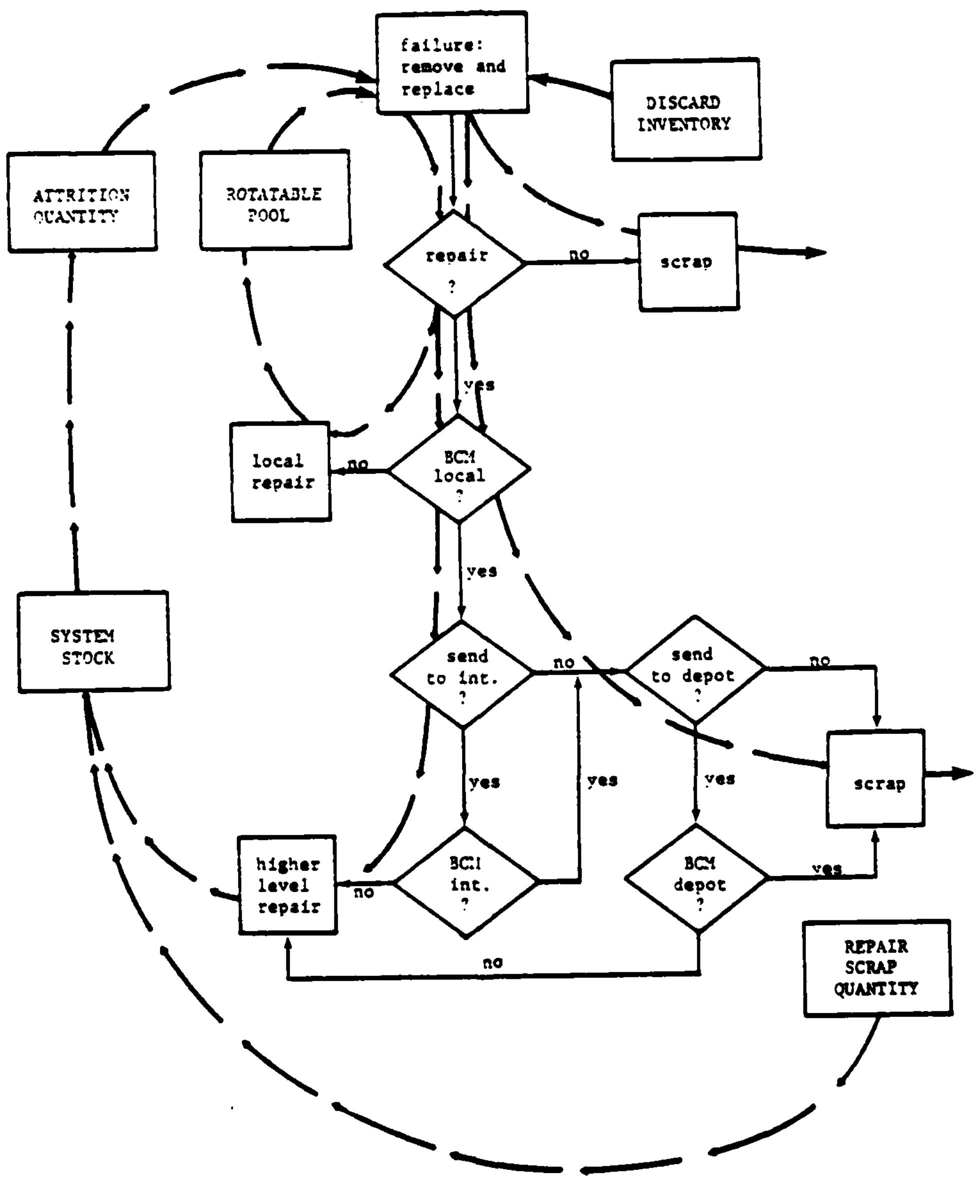


on-site quantity is divided into two separate inventories: the rotatable pool against assemblies being repaired at the operational site; and the attrition quantity against assemblies being repaired at a higher level maintenance activity. The sizes of the rotatable pool and attrition quantities are predicated on the repair cycle times for local repair and off-site repair, respectively. Both quantities are subject to integerization rules to provide a buffer stock as insurance against stock outs.

There are two other inventory stocks for the repair alternative: the system stock and the repair scrap quantities. The system stock quantity is a safety inventory quantity to cover excess demands on the maintenance pipeline. The repair scrap quantity replaces all items permanently lost to the maintenance system because they have been condemned.

Figure A-3 shows the roles of the rotatable pool, attrition, system stock, repair scrap, and discard inventory quantities in the flow of spares as modeled by AIR.

Figure A-3. Maintenance Pipeline Flow in the AIR Model



Maintenance Wage Costs in AIR

AIR calculates labor costs for seven different cases: discard; local repair; intermediate repair, higher assembly coded local repair; intermediate repair, higher assembly coded intermediate repair; depot repair, higher assembly coded local repair; depot repair, higher assembly coded intermediate repair; and depot repair, higher assembly coded depot repair.

This is done in order to distinguish between the number of discard and/or remove and replace actions which would take place at any given level of maintenance activity. For example, even though the same number of assemblies will have to be removed and replaced regardless of the repair posture of the assembly, it costs more in direct labor charges to remove the assembly at the depot than at the operational site because the cost per man hour at the depot is higher than on a CV or at an air station.

In calculating the total labor costs associated with an equipment, the model begins with the sub-assemblies contained in the equipment which are at the lowest level of indenture. Only the direct labor on the sub-assembly is included in the cost. If, for example, the higher assembly is removed at the operational site and sent to the depot for repair, where the sub-assembly is removed, only the cost of removing the sub-assembly from its higher assembly and of repairing or discarding that sub-assembly is counted. The cost of work on the higher assembly is included in a later iteration of the model in which the higher assembly is now considered to be the sub-assembly. The assumption is correctly made that the number of manhours required to fault isolate, remove and replace a failed item are the same for both discard and repair options.

Training Costs in AIR

AIR computes training costs at five different maintenance activities: squadron, carriers, Naval Air Stations, Prime-Intermediate Maintenance Activities (Naval Air Stations with additional repair facilities), and depots. The input values for the number of men and costs of training at each of these sites are supposed to vary for each of the four LOR alternatives considered. However, it is not at all clear how it would be possible to arrive at values for these inputs when they are, in fact, direct functions of the total maintenance requirement of the system, which is determined by the complicated mix of LOR postures for each of the modules which make up the system.

A.3 NAVAL ELECTRONIC SYSTEMS COMMAND EQUIPMENTS MODEL

The Naval Electronic Systems Command Equipments Model (herein referred to as ELEX) is, after AIR, the most widely used of the 1390B models.

ELEX recognizes a single level of indenture. It deals with an item, called an assembly, and compares the economic impact of three LOR alternatives for that item: intermediate repair, depot repair, and discard. By altering some of the input parameters, it is possible to convert the cost equations for intermediate maintenance into an organizational maintenance alternative. There is no BCM (Beyond Capability of Maintenance) rate; items which cannot be repaired at the maintenance activity for which they are coded are always scrapped, rather than being sent to a higher level of repair.

ELEX is the only one of the four 1390B models reviewed which includes both a discound and inflation factor.

Assembly Inventory

The assembly inventory cost in ELEX is the summation of three separate inventory costs: the allowance quantity, system stock requirement, and replenishment quantity. The role of these stock inventories has already been discussed in previous sections. At this time we will take a closer look at the computational routine used to compute the size of the allowance quantity. This formulation is important because (1) it is widely used (the stockage requirements in the SEAFIRE model, for example, are derived from this formula); and (2) it is wrong.

The formulae for computing the allowance quantity originate from the FLSIP (Fleet Logistics Support Improvement Program). In adapting them to the ELEX model, the explicit assumption has been made that the repair cycle times for sea and shore operational sites are both equal to one quarter. The formulae for allowance quantity in ELEX are:

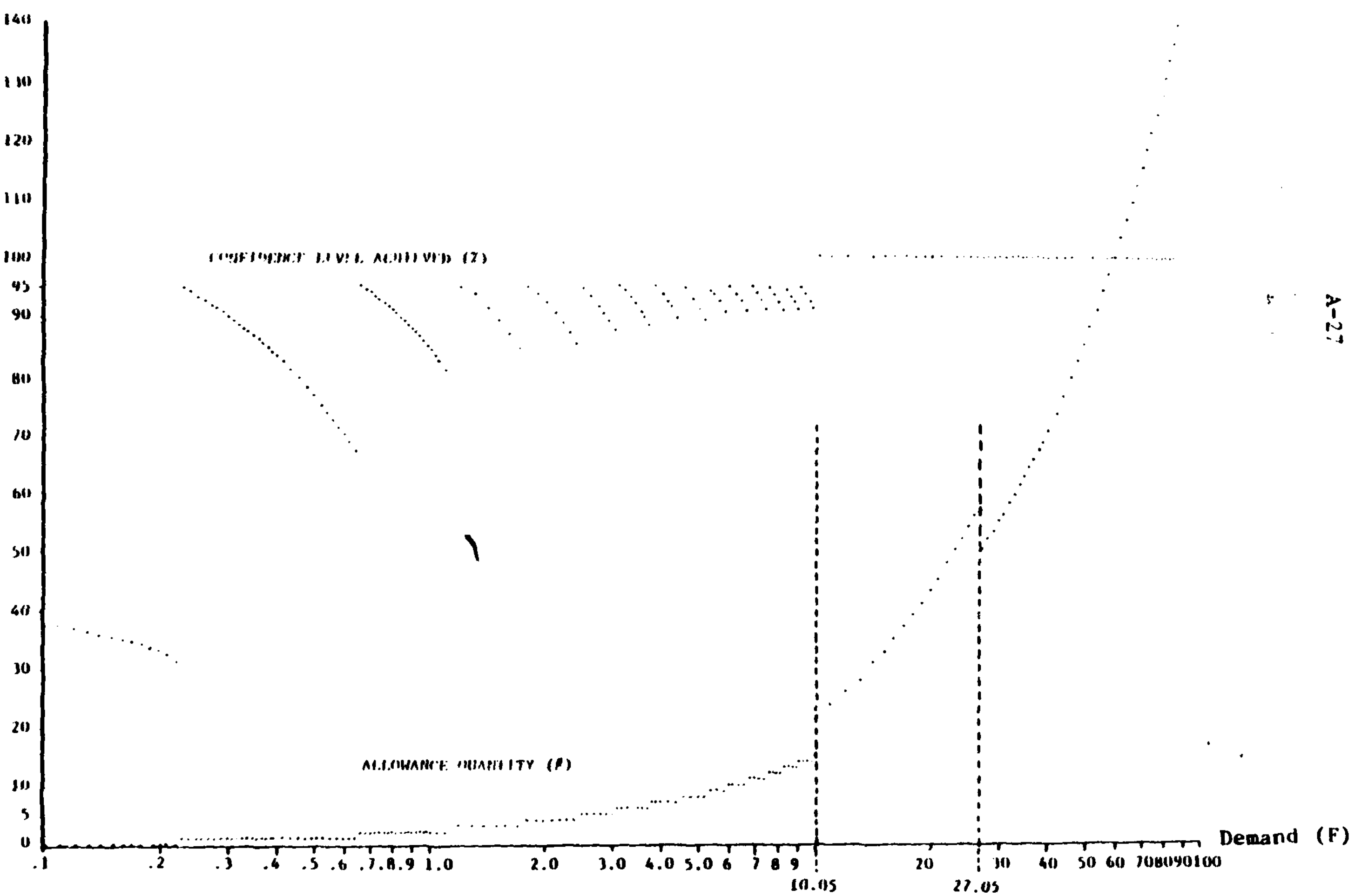
$$\text{Allowance Quantity} = \begin{cases} 0 & F \le .222 \\ \text{Int } (F + 1.645\sqrt{F}) & .222 \le F \le 10.05 \\ \text{Int } (F + 1.45\ F^{.934}) & 10.05 \le F \le 27.05 \\ \text{Int } (1.5\ F + 10) & 27.05 \le F \le 100 \\ \text{Int } (1.6\ F) & F > 100 \end{cases}$$

where F is the expected number of failures per quarter of the assembly. For $F \le .222$ the allowance quantity may be set equal to one if a Technical Override Requirement or Military Essentiality Code is applied.

A graph of the allowance quantities and resulting confidence levels achieved as a function of F is provided in Figure A-4.

There are several points to be made about the allowance quantity computations. First, note that there are large gaps in the allowance quantities purchased at the 10.05 and 27.05 decision points. The formula implies, for example, that at $F = 10$ one should buy 15 spares, while at $F = 11$ one would have to buy 22 spares. The implication of this is that the designer using the ELEX model as a tradeoff tool might be induced--quite erroneously--to spend unwarranted time and effort attempting to reduce the failure rate of an assembly from 11 to 10 failures per quarter.

Figure A-4. Allowance Quantity and Confidence Level as a Function of Demand



For $F \leq 10.05$, the range which includes the failure rates of almost all modern electronic equipments, ELEX consistently buys fewer spares than are needed to achieve a 95 percent confidence level against stock out. In fact, at $F = .222$ the confidence level achieved by using the ELEX spares criterion drops to less than 30 percent, which implies that two-thirds of the time the system will suffer a stock out of that assembly. On the other hand, due to the large upward gap at $F = 10.05$, from that point on ELEX consistently buys far more spares than are necessary for a 95 percent confidence level. Very few equipments are likely to have such a high failure rate, however.

The practice of using different distributions to compute the allowance quantity for different ranges of equipment failure rate is methodologically suspect. Equipment failure rates follow a single arrival distribution, called a Poisson distribution, for all values of the failure rate. It is possible to approximate this distribution (which is difficult to use because it requires iterative calculations) using a simpler formulation based on the normal distribution. Once again, however, this approximation is applicable over the entire range of equipment failure rates. The formulae used to compute the allowance quantity in ELEX are merely garbled forms of this approximation.

The final point to be made is that even if the allowance quantities for each of the assemblies in a system were correctly computed for a 95 percent confidence level against stock-out, the allowance quantity for the system would still be low. A system consisting of ten assemblies, for

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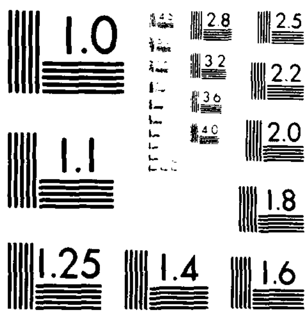


MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963-A

example, where each has a 95 percent confidence level against stock-out, has a 60 percent chance of incurring an outage for the system. The Navy attempts to buy spares to a system confidence level (though this is rarely actually accomplished). It is therefore true that the actual spares cost for a new system is grossly understated by independent computations on a part-by-part basis.

Training Costs in ELEX

Unique among the four 1390B models reviewed, ELEX has an integerization routine for computing the number of trained men. After calculating the number of trained men for each assembly in the system, this quantity is summed for all the assemblies. If this sum is less than one trained man for each maintenance activity site, then it is set equal to one man per site. If, on the other hand, the total number of men to be trained is greater than this minimum (one per site), it is rounded up to the next higher integer. After the total has been adjusted, it is reapportioned over all the assemblies in the same ratio as it was originally calculated.

This routine is useful, but not completely correct. The number of men to be trained should be computed and rounded up on a *per site* basis. For example, if there is a maintenance requirement of 1.15 men per site at each of ten sites, then the correct number of men to be trained is two men per site for a total of twenty men; *not* 12 men as the interization option of ELEX would indicate.

A.4 NAVAL SEA SYSTEMS COMMAND SHIPS EQUIPMENT MODEL

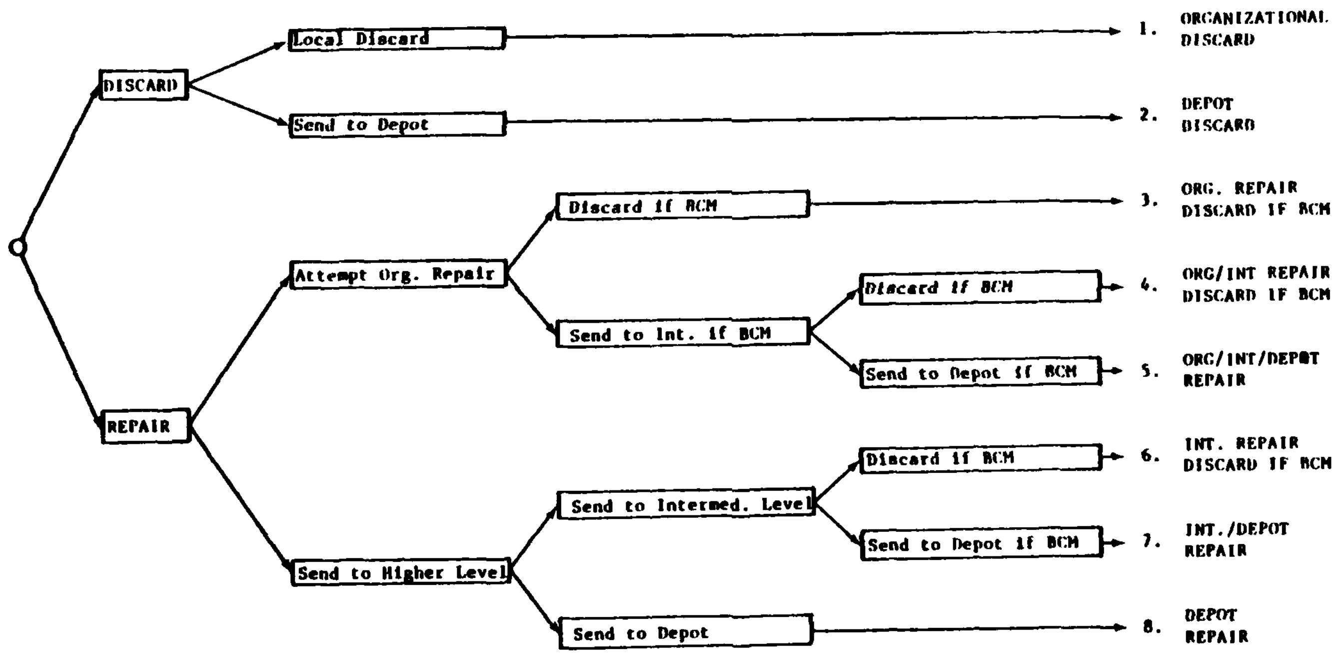
The Naval Sea Systems Command Ships Equipment Model (herein referred to as SHIPS), can be noted for making more distinctions in LOR alternatives than any of the other 1390B models, and for having more conceptual and mathematical errors in it than the others.

SHIPS is a single-indenture level model. It considers three levels of repair: organization level, i.e., aboard ship; intermediate level, either afloat or ashore; and depot level. These three levels of repair are combined into eight possible LOR postures, which are presented in Figure A-5.

Because of the large number of LOR alternatives considered in SHIPS, the mathematical structure of the cost equations is very complex. Often a single cost element is represented by several different equations, each applicable to only one or two of the LOR alternatives. These formulations are replete with errors, both arithmetic and conceptual. The values which are incorrectly computed in SHIPS due to these errors include: external demands on the maintenance pipeline, total consumption quantity, total number of items salvaged per type, number of repairs, and transportation and packaging costs.

Much of the complexity of the cost equations in SHIPS is unnecessary. Considerable simplification could be accomplished if the eight LOR alternatives used in SHIPS were specified by the use of the following parameter conventions:

Figure A-5. LOR Alternatives in the Ships Equipment Model



Let,

1) BCM_x = Beyond Capability of Maintenance Rate

where $\begin{cases} x = 0\text{: organizational level of repair} \\ x = I\text{: intermediate level of repair} \\ x = D\text{: depot level of repair} \end{cases}$

2) FSR = Field Survival Rate

FSR is set to 1 whenever the support posture does not include a depot.

The parameter values required to portray each posture in SHIPS are:

Posture	BCM_O	BCM_I	BCM_D	FSR
1	1	1	1	1
2	1	1	1	FSR
3	S	1	1	1
4	B	S	1	1
5	B	B	S	FSR
6	1	S	1	1
7	1	B	S	FSR
8	1	1	S	FSR

S: Scrap rate
B: Proportion of reparable generations beyond capability of repair.

As an example of the application of this parameter convention, take the calculation in SHIPS of a quantity called the total consumption quantity per type. The cost equations presently used contain several errors and require three pages of text to account for all the LOR alternatives. Using the parameter convention, the cost calculation can be reduced to a single equation:

$$\begin{pmatrix}\text{Total}\\ \text{consumption}\\ \text{quantity}\\ \text{per type}\end{pmatrix} = \begin{pmatrix}\text{Total number}\\ \text{of replacements}\\ \text{per type}\end{pmatrix} (BCM_0\ BCM_I\ (1-FSR) + BCM_D\ FSR).$$

There is one final point which must be made about the model. SHIPS deliberately excludes all wage and training costs associated with the fault isolation, removal and replacement of an assembly. The rationale behind this omission is that this cost "...would be added equally to all decision alternatives, and therefore is not a function of level of repair." The biases introduced to any kind of tradeoff analysis, including LOR alternative comparisons, were discussed in Chapters 2 and 3 of this volume.

$$\begin{pmatrix}\text{Total}\\ \text{consumption}\\ \text{quantity}\\ \text{per type}\end{pmatrix} = \begin{pmatrix}\text{Total number}\\ \text{of replacements}\\ \text{per type}\end{pmatrix} (BCM_0\ BCM_I\ (1-\bar{F}SR) + BCM_D\ FSR).$$

There is one final point which must be made about the model. SHIPS deliberately excludes all wage and training costs associated with the fault isolation, removal and replacement of an assembly. The rationale behind this omission is that this cost "...would be added equally to all decision alternatives, and therefore is not a function of level of repair." The biases introduced to any kind of tradeoff analysis, including LOR alternative comparisons, were discussed in Chapters 2 and 3 of this volume.

A.5 NAVAL SEA SYSTEMS COMMAND ORDNANCE EQUIPMENT MODEL

The Naval Sea Systems Command Ordnance Equipment Model (from now on referred to as ORD), is a single indenture level model which compares the economic impact of four LOR alternatives: organizational repair, intermediate repair, depot repair, and discard. As in the Electronics Model, there is no BCM rate: items which cannot be repaired at a maintenance activity are automatically scrapped without the option of sending them to a higher level of repair.

The structure of ORD is very close to the generalized structure of the 1390B models presented at the beginning of this appendix. There are, however, three differences which are worthy of mention. First, the allowance quantity as calculated in ORD can be stored either at the operational site (in which case it is called a First Echelon Support Requirement, FESR) or at a tender or depot (in which case it's called a Second Echelon Support Requirement, SESR), but not both. Both the FESR and SESR are computed using the same allowance quantity formulae discussed in Section A.3, and thus have the same problems associated with them.

When calculating maintenance wage costs associated with the repair postures, ORD omits the cost of fault isolation, removal and replacement of the assembly. This omission is not neutral with regard to support policy options: it biases the user toward a repair posture by understating the cost of repair compared to discard.

Finally, ORD uses two different methods to determine the number of men who require initial training. The first method is the one described

in the body of the report: total maintenance hours required are divided by total maintenance hours available. The second method requires as input the total number of trained men required for the entire system. The model divides that number by the total number of assemblies to arrive at an average number of trained men per assembly. ORD then takes the maximum of the two quantities computed to be the value for the number of trained men.

APPENDIX B. EQUIPMENT MODEL

B.1 NAVMAT LIFE CYCLE COST GUIDE FOR EQUIPMENT ANALYSIS

The Life Cycle Cost Guide for Equipment Analysis (herein referred to as the Equipment Model), was developed by the Cost Management Division of the Management Engineering Department, Naval Weapons Engineering Support Activity (NWESA).

One of the most important features of the model is that it is designed to be flexible: the computer program on which the model is implemented enables the analyst to modify the Standard Equipment Model to his specific needs without making any program changes. Changes in the equation structure of the model are accomplished by inputing them as data to the program. It is possible to alter the entire cost structure of the model using the FLEX technique. A detailed discussion of the FLEX technique is provided in Section 3 of this appendix. This appendix will review the standard cost structure of the Equipment Model.

The model produces eight output reports. These reports are:

1. Summary
2. Funding by Cost Category
3. Cost Breakdown by Year
4. Cost Breakdown Totals
5. General Funding
6. Annual Cost by Funding Type
7. Annual Cost by Cost Category
8. Sensitivity Analysis

The total life cycle cost as calculated in the Equipment Model is the sum of three major cost elements: Research and Development, Investment, and Operating and Support. These cost elements are calculated as the sum of 61 basic cost equations, which require 104 cost factor inputs.

Each cost equation in the Equipment Model is assigned to one of ten cost categories. These cost categories and their numerical codes are:

1. Contractor Payment
2. Program Management
3. Testing
4. Prime Equipment
5. Training
6. Supply Support
7. Technical Data
8. Support Equipment
9. Operation
10. Maintenance

Each cost equation is assigned to one of six funding types. These types are:

1. Research and Development
2. Procurement
3. Construction
4. Operation and Maintenance
5. Military Personnel
6. Others

Each cost equation can be adjusted by one of four inflation factors appropriate to research and development, procurement, construction, or operation and maintenance. A discount rate is also used. The form of the adjustment factor is:

$$\left(\left(\frac{1 + I}{1 + D}\right)^{n-1} + \left(\frac{1 + I}{1 + D}\right)^{n}\right) \div 2$$

where I is the inflation rate and D is the discount rate. The value of n is the year in the life cycle in which a cost is incurred. This formulation converts calendar years to fiscal years.

Each cost equation is also assigned a cost breakdown structure number which determines the position of the equation in the cost aggregation hierarchy. The cost of an element is the sum of the indentured elements below it. For example, CBS number 120000 (Full-Scale Development) is defined by the model as the sum of CBS numbers 121000 (contractor) and 122000 (government); CBS 122000 is the sum of CBS 122100 and 122200, and so on. This requires that only those cost elements which do not have lower indentured cost elements need be described by equations; the cost breakdown structure of the model automatically takes care of aggregation. The standard life cycle cost breakdown structure is presented in Table B-1.

The model calculates the cost of each equation for each year of the life cycle of the equipment. Once the cost for each year is calculated, it is then adjusted by the discount/inflation factor.

Table B-1. Equipment Model Cost Breakdown Structure

CBS NO		Cost Cat.	Fund Type	Infl. Type
000000	TOTAL LIFE CYCLE			
100000	RESEARCH AND DEVELOPMENT			
110000	Validation			
111000	Contractor	1	1	1
112000	Government	2	1	1
120000	Full Scale Development			
121000	Contractor			
121100	Management	1	1	1
121200	Engineering	1	1	1
121300	Prototype Hardware	1	1	1
121400	Software	1	1	1
121500	Test & Evaluation	1	1	1
121600	Documentation	1	1	1
121700	Support & Test Equipment	1	1	1
122000	Government			
122100	Program Management	2	1	1
122200	Prototype Test & Evaluation			
122210	Training	5	5	4
122220	Test Site Activation	3	3	3
122230	Test & Evaluation	3	1	1
200000	INVESTMENT			
210000	Government Program Management	2	2	1
220000	Prime Equipment Acquisition			
221000	Production Hardware	4	2	2
222000	Production Support & Services	4	2	2
223000	Production Test & Evaluation	3	2	2
224000	Transportation	4	2	2
225000	Installation and Checkout	4	2	2
230000	Initial Support Acquisition			
231000	Support & Test Equipment Acquisition	8	2	2
232000	Supply Support			
232100	Initial Spares			
232110	Prime Equipment	6	2	2
232120	Support & Test Equipment	6	2	2
232200	NSN Entry into the Supply System	6	4	4
233000	Facilities			
233100	Operational	9	3	3
233200	Maintenance	10	3	3
234000	Documentation			
234100	Acquisition	7	2	2
234200	Reproduction and Distribution	7	2	2
235000	Training			
235100	Operator	5	5	4
235200	O/I level Maintenance	5	5	4
235300	Depot level Maintenance	5	4	4
235400	Instructor	5	5	4
235500	Training Aids	5	2	2

Table B-1. Equipment Model Cost Breakdown Structure (cont'd)

CAS NO		Cost Cat.	Fund Type	Infl Type
300000	OPERATING AND SUPPORT			
310000	Operation			
311000	Personnel	9	5	4
312000	Facilities	9	3	3
313000	Energy Consumption	9	4	4
314000	Material Consumption	9	4	4
315000	Software Maintenance	9	4	4
320000	Support			
321000	Corrective Maintenance			
321100	Labor			
321110	O/I level (Remove & Replace)	10	5	4
321120	O/I level (Repair)	10	5	4
321130	Depot level (Repair)	10	4	4
321200	Repair Material	10	4	4
321300	Transportation and Packaging			
321310	Material Handling Labor	10	4	4
321320	Packaging Material	10	4	4
321330	Shipping	10	4	4
322000	Preventive Maintenance			
322100	Labor	10	5	4
322200	Material	10	4	4
323000	Overhaul			
323100	Labor	10	4	4
323200	Material	10	4	4
323300	Transportation	10	4	4
324000	Support & Test Equipment Maintenance	10	4	4
325000	Facilities			
325100	Shop Space			
325110	O/I level	10	3	3
325120	Depot level	10	3	3
325200	Inventory Storage			
325210	O/I level	10	3	3
325220	Depot level	10	3	3
326000	Documentation Maintenance	7	4	4
327000	Supply Support			
327100	Replenishment Spares	6	4	4
327200	Supply System Management	6	4	4
328000	Training			
328100	Operator	5	5	4
328200	O/I Level Maintenance	5	5	4
328300	Depot Level Maintenance	5	4	4
330000	Termination	6	4	4

B.2 THE EQUATION STRUCTURE OF THE EQUIPMENT MODEL

1. Research and Development

Research and development is divided into two major sub-costs: validation and full-scale development. Each of these is further divided into contractor and government supported costs. All the cost elements in research and development are throughputs. The input variables are summed directly into total cost for each year of the equipment life cycle. A typical example is CBS 121100, Contractor Management costs during full-scale development, which is defined as:

$$\sum_{I=1}^{Y} DCPM(I)$$

where I is the designator for a specific project year; Y is the number of years covered by the life cycle cost analysis; and DCPM(I) is payment by the Government for management effort during full-scale development in year I.

In the definition of DCPM(I), it is noted that this cost includes the cost of personnel, services, overhead associated with cost/schedule control, configuration management, data management, contract management, and ILS management. In the standard model, the estimation of these costs is external to the model. In a more detailed version of the Equipment Model, these costs could each be handled explicitly (see the description of the FLEX technique later in this appendix).

2. Investment

Investment is divided into three major cost categories: program management, prime equipment acquisition, and initial support acquisition. Most of the cost elements in investment are either throughputs of the same form as that described above, or are of the form (number of X) times (cost per X). A typical example of the second form is CBS 235100, initial operator training costs, which is calculated as

$$\sum_{I=1}^{Y} PTO(I) * CTO$$

where PTO(I) is the number of operationg personnel to receive initial training in year I and CTO is the average cost of operating personnel training.

The one exception to this rule is the acquisition cost of primary equipment initial spares. Based on the failure rate for the modules of the equipment, spares are bought for the rotatable pool, attrition quantity, and system pipeline stock. Replenishment spares are allocated to operating and support. The model does not include the purchase of any buffer stock which would be used as insurance against variations in the failure rate of the modules, so the estimated cost of spares would be uniformly low unless proper adjustments were made to the required stockage times at the O/I level. (For a detailed discussion of spare stockage, see the discussion of the 1390B models in Appendix A.)

3. Operating and Support

Operating and support is divided into three major cost categories: operation, support, and termination. The major sub-categories of support are maintenance, facilities, documentation, supplies, and training (attrition related). Most of the costs included under maintenance are computed in the following generalized form:

NUM(I) * OT * COST/MTIME

where NUM(I) is the number of items at the end of year I, OT is the operating time of the item per year, and COST is the average cost of a maintenance action. The cost may be the cost of labor, material, shipping, packaging, overhaul, etc. For labor cost, it is computed as the product of the manhours needed to accomplish the action and an hourly wage rate. MTIME is the average time between the maintenance actions. With the exception of scheduled preventative maintenance, MTIME is equal to the product of the mean time between failure of an item and a reliability improvement/degradation factor.

B.3 MANPOWER COSTS IN THE EQUIPMENT MODEL

The Equipment Model calculates manpower costs in three major categories: training, operator wages, and maintenance wages. These categories are further divided into sub-categories by type of action and site. A listing of the manpower elements of the Equipment Model cost breakdown structure is provided in Table B-2.

Training

Initial training costs are computed using the following formula:

$$\text{Training cost} = PT_i(I) * CT_i$$

where I is the designator for a specific project year; $PT_i(I)$ is the number of i type personnel (*i = operator*, *O/I maintenance*, depot maintenance, instructor) to receive initial training in year I; and CT_i is the cost of training i type personnel.

This is a very straightforward equation, and there is nothing wrong with it. However, when attrition-related training is calculated, a different input variable is used for the number of men to be trained. The formula is:

$$\text{Attrition training} = L_i(I) * CT_i * RA_i$$

where $L_i(I)$ is the "desired manning level" of type i personnel (i = operator, O/I maintenance, depot maintenance; note that instructors are *not* included) in year I; and RA_i is the attrition rate for type i personnel.

$PT_i(I)$ and $L_i(I)$ are simply two different ways of looking at the same thing; namely, the number of men who must be trained each year.

Table B-2. Manpower Cost Categories in the Equipment Model

I. Training

A. Initial

1. Operator

2. O/I level maintenance

3. Depot level maintenance

4. Instructor

B. Attrition Related

1. Operator

2. O/I level maintenance

3. Depot level maintenance

II. Operator Wages

III. Maintenance Wages

A. O/I level

1. Fault isolate, remove and replace

2. Repair

3. Preventative

B. Depot level

1. Repair

2. Overhaul

Now, certain relationships must hold between $PT_i(I)$ and $L_i(I)$ for them to be logically consistent; namely:

$$\sum_{I=1}^{I'} PT_i(I) = L_i(I') \text{ and } PT_i(I) = \max \begin{cases} L_i(I+1) - L_i(I) \\ 0 \end{cases} \quad \text{for } I \geq I'$$

where I' is the year in which the equipment is first deployed.

The logic behind these relationships is the following. If $L_i(I')$ personnel are needed to man the equipment when it is first deployed, then $L_i(I')$ men must be trained before deployment; hence the first relationship. From then on, if the deployment level of the equipment in year I ($I \geq I'$) increases to require $L_i(I+1) - L_i(I)$ additional men, then that is the number of extra men who will have to receive initial training during that year (remember that $PT_i(I)$ does not include attrition-related training), whereas if the system size remains constant or decreases, no additional men will be trained.

The relationships between $PT_i(I)$ and $L_i(I)$ may be exploited to eliminate the need to input both variable vectors to the model. This may be especially useful if one wishes to use the Equipment Model for manpower tradeoffs. In this case, it is desirable to be able to affect manpower costs by changing as few variables as possible. This can be done by having the model calculate the relationships between the variables for the user. Keeping this in mind when reviewing the cost equations for operator and maintenance personnel labor, we will indicate how the factors used in calculating these costs can be adapted to calculate values for $L_i(I)$, the desired manning level. Since $PT_i(I)$ can be determined from

$L_i(I)$, it would be possible, if desired, to completely eliminate the need to input these two variables: the model would automatically compute training manpower requirements for the user.

Operator Wages in the Equipment Model

Personnel pay and allowance costs incurred each year by the equipment operators are computed using the following formula:

$$\text{Operator pay} = N(I) * PO * RO * OT$$

where N(I) is the number of equipments at the end of year I, PO is the number of operators per equipment, RO is the operator hourly pay rate, and OT is the equipment operating time per year. Note that the product of N(I) and PO can be used to calculate the desired manning level for equipment operators, $L_{op}(I)$, and thus can be used to replace this input parameter. A demonstration of how the FLEX technique can be used to make such changes in the equations of the Equipment Model will be presented later in this appendix.

Maintenance Wages in the Equipment Model

A generalization of the formulas used in the Equipment Model to calculate maintenance labor costs is the following:

$$\text{Maintenance wage} = N(I) * R_a * OT * P_b/M_a$$

where R_a is the required number of manhours to perform a maintenance action of type a (a = I/O remove and replace, I/O repair, I/O scheduled maintenance, depot repair, depot overhaur), P_b is the hourly maintenance personnel pay rate at a facility of type b (b = I/O, or depot), and M_a is the mean time between maintenance actions of type a. This is a standard formula for computing maintenance wage costs which we can recognize from our previous discussions.

The factor $N(I) * R_a/M_a$ is the number of maintenance manhours of type a required for every hour of equipment operation. This factor can be used to compute the required number of maintenance personnel to be trained at each level of maintenance activity. For example, $L_{depot}(I)$, the desired manning level of depot level maintenance personnel, can be calculated as a function of the sum of the factor $N(I)\ R_a/M_a$ for a = depot repair and a = depot overhaul. A similar calculation would yield the total number of operational level maintenance personnel required to be trained.

It is tempting to plunge ahead and use the FLEX technique provided with the Equipment Model to make modifications to the Standard Equipment Model such as the ones which have just been described. However, certain difficulties may arise if one attempted to so so. For example, notice that the relationship between $PT_i(I)$ and $L_i(I)$ requires logical processing

(if I is greater than I' then ...), which the present version of the model is not capable of handling. The next section discusses the FLEX technique in some detail.

B.4 THE FLEX TECHNIQUE FOR THE EQUIPMENT MODEL

Using the FLEX technique, the user of the Equipment Model can alter the entire equation structure of the model if he wishes without making any changes in the program code. The FLEX options open to the user are the following:

1. Maintain a cost element but change its description, cost category, funding type or inflation factor type;
2. Introduce a new cost element either as the sum of existing cost elements or as a new equation;
3. Delete an existing cost element; or
4. Introduce new input variables.

There is one important limitation in making changes to the equations of the Equipment Model. All equations are input to the model in reversed Polish notation (RPN), familiar to many because of its use in some calculators. In RPN, the sequence A, B, C, +, * is equivalent to A*(B+C). Only equations which can be expressed in this fashion can be input to the Equipment Model. It is not possible to input equations which require logical flow processing (for example, "if less than zero then set equal to zero"). This is often required to integerize (useful for determining spares and manpower requirements), or to save intermediate variables (useful for avoiding redundant computation: not a trivial consideration if the user must input long, complicated equations several different times in the model).

The following is a simple example of the use of the FLEX technique. In the standard model, attrition-related training costs for operators are given by the following equation:

$$\text{CBS } 328100 = \sum_{I=1}^{Y} \text{LO(I)} * \text{RAM} * \text{CTO}$$

where LO(I) is the manning level of operating personnel during year I, RAM is the personnel attrition rate, CTO the operator training cost, and Y the years in the equipment life cycle.

Rather than having the manning level as an input variable, the program analyst might wish to compute its value from the number of equipments. Specifically, let us replace the value of LO(I) in the equation above by the value

$$\text{LO(I)} = \text{N(I)} * \text{PO}$$

where N(I) is the prime equipment inventory during year I, and PO is the number of operators per prime equipment.

These variables N(I) and PO are input variables to the standard model (in fact, they are used to compute operator wage costs), so it is not necessary to introduce them as new variables.

The changes in the equation can be accomplished by including two cards in the input data list for the program. These cards are:

```
CS328100    1
EQ328100    N(I), PO, RAM, CTO, *, *, *; I, 1, Y
```

The first card indicates that a change is requested in cost breakdown structure equation number 328100. The second card states that the new form for the equation is:

$$\sum_{I=1}^{Y} \text{N(I)} * \text{PO} * \text{RAM} * \text{CTO}.$$

There are three general categories in which the FLEX technique has great potential for use. The example given above belongs to the first category. As in the example, it is possible to alter specific equations. Reasons for such changes might include substituting new input data element for the standard element; enhancing the sensitivity of the model to certain variables as in the example, and adding or deleting cost elements specific to a particular project (for example, one may wish to add security clearances for equipment operators).

The user may also wish to introduce aggregation level changes. This would allow several different versions of the Equipment Model to be used at different stages of the design process. For example, at the early part of the design process, accurate data on support costs might not be available. The analyst may create a simple model for use at this time which delete all the sub-cost elements under Initial Support Acquisition (CBS 231000 - CBS 235500) and create a simple throughput for the entire cost of support acquisition. Another version of the model for use later in the design process may include some or all of these sub-costs, or break the cost down into more detailed cost elements as they become available.

Finally, the analyst may wish to change the output of the Equipment Model to be suitable for use as input to other models such as the Major Weapon System Model. Similarly, the inputs to the model might be altered to be compatible with the output of other models.

While the FLEX technique makes changes of the sort noted *possible*, it does not make them simple to carry out. In addition, most of the changes which would be desirable would require the extensive application of cost-analytic expertise. Even if the availability of such expertise could be taken for granted (which it can't), the uniformity of the output structure would create a very false impression of comparability.

Essentially, the Equipment Model (as well as the Major Weapon System Model discussed in Appendix C) is not a model at all, but a budget accounting structure. The use of the FLEX technique makes it possible to impose some of the features of a cost model on the program. But there are grave shortcomings--lack of methodological guidelines, difficulty of introducing specific model structures, appearance of comparability and sheer size--which make it unlikely that either of these programs will completely satisfy the requirement for linked and graded models suitable to every stage of the weapon system acquisition process.

APPENDIX C. MAJOR WEAPON SYSTEM MODEL

C.1 LIFE CYCLE COST GUIDE FOR MAJOR WEAPON SYSTEMS

The Life Cycle Cost Guide for Major Weapon Systems was developed for the Naval Material Command by the Cost Management Division of the Engineering Management Department, Naval Weapons Engineering Support Activity. It is intended to provide a framework for comparison of research and development, investment, and operating and support costs of program design, or support alternatives of a major weapon system.

The Major System Model should be considered a guide to aid in achieving a consistent framework for estimating life cycle costs of major weapons systems, including both aircraft and ship systems; not a rigid specification for life cycle cost analysis. The intended use of the model is to provide "buckets" for most or all of the important costs associated with a system; and to allow the user to estimate the values of these buckets as he sees fit, incorporating that estimation into the model using the FLEX technique. To this end, each of the standard input parameters to the model has associated with it a description of the elements which make up the parameter. However, these descriptions, which are often extremely detailed, do not include methodological guidelines for estimating the values of the elements.

The documentation associated with the model offers four examples of possible applications of the major systems model, and how the model might be adapted to these uses. These applications are:

1. Compare the LCC of two proposed weapons systems in similar stages of development. In this case the level of detail of the cost breakdown structure would be adjusted according to the stage of development of the weapon systems; cost elements also may be altered to reflect specific differences in the systems' design.

2. Compare the cost of modifying an existing weapon system to that of developing and acquiring a proposed new weapon system. Two versions of the model might be prepared. The model for the existing system would emphasize operating and support, with historical data used for development and acquisition costs. The model for the proposed system would emphasize acquisition costs, with operating and support costs estimated at a more aggregate level.

3. Compare two different component designs. Costs not directly associated with the component may be deleted to allow greater visibility of component-specific costs.

4. Compare two different support concepts. The model would focus on operating and support costs; a series of LOR policy switches might be added to the model to facilitate comparison of alternatives.

C.2 STRUCTURE OF THE MAJOR WEAPON SYSTEMS MODEL

The Major Weapons Systems Model divides total life cycle costs into five major cost elements: research and development, investment, operating and support, associated systems, and termination. The Standard Cost Breakdown Structure is very similar to that of the Equipment Model, but has differences which indicate that a higher level of aggregation is being dealt with. A copy of the Cost Breakdown Structure of the Major Systems Model is provided in Table C-1.

Cost estimates using the Major Systems Model can be made at three different hardware indenture levels: component, subsystem, or total weapon system. Which aggregation indenture level is chosen would depend on the stage of development of the system. The model suggests five generic subsystems into which the total weapon system may be divided: structure, electronics, propulsion, armament, and other.

Each cost element is calculated in constant dollars for each year of the system life cycle. These costs are then adjusted by a discount/inflation factor which is identical in form to that used in the Equipment Model (see Appendix B of this volume). Each cost equation has associated with it one of ten cost categories and one of six funding types. Costs can be adjusted by one of four inflation factors exactly as in the Equipment Model. The logic behind the Cost Breakdown Structure hierarchy is also the same as that in the Equipment Model.

The costs calculated in the model are the sum of 77 basic cost equations, which require 109 cost factor inputs. Not all of the cost elements

Table C-1. Major Weapon System Model Cost Breakdown Structure

1.	RESEARCH AND DEVELOPMENT
1.1	VALIDATION
1.11	CONTRACTOR
1.12	GOVERNMENT
1.2	FULL SCALE DEVELOPMENT
1.21	CONTRACTOR
1.211	PROGRAM MANAGEMENT
1.212	ENGINEERING
1.213	PROTOTYPE HARDWARE
1.214	SOFTWARE
1.215	INTEGRATION AND TEST
1.216	DOCUMENTATION
1.22	GOVERNMENT
1.221	PROJECT MANAGEMENT
1.222	SYSTEMS ENGINEERING
1.223	SYSTEM TEST AND EVALUATION
1.2231	TEST PERSONNEL AND TRAINING
1.2232	TEST SAMPLES
1.2233	TEST AGE/GSE/TE
1.2234	TEST FACILITIES
1.224	FOREIGN MILITARY SALES
2.	INVESTMENT
2.1	ACQUISITION (CONTRACTOR)
2.11	PRODUCTION HARDWARE
2.12	PECULIAR SUPPORT EQUIPMENT
2.13	TRAINING
2.14	INTEGRATION AND TEST
2.15	PROGRAM MANAGEMENT
2.16	DOCUMENTATION
2.17	TECHNICAL SUPPORT
2.18	INDUSTRIAL FACILITIES
2.19	INITIAL SPARES AND REPAIR PARTS
2.2	GOVERNMENT
2.21	SELECTED
2.22	COMMON SUPPORT EQUIPMENT
2.23	TRAINING
2.24	SYSTEM TEST AND EVALUATION
2.25	PROJECT MANAGEMENT
2.26	DOCUMENTATION
2.27	SITE ACTIVATION
2.271	OPERATIONAL SITES
2.272	MAINTENANCE FACILITIES
2.28	SUPPLY INTRODUCTION
2.29	TRANSPORTATION
3.	OPERATING AND SUPPORT
3.1	OPERATING
3.11	CREW
3.12	STAFF
3.13	MATERIAL
3.14	SECURITY
3.15	OTHER DEPLOYED MANPOWER
3.16	PERSONNEL SUPPORT
3.2	ORGANIZATIONAL/INTERMEDIATE MAINTENANCE ACTIVITY
3.21	AFLOAT FACILITIES
3.211	LABOR
3.2111	WEAPON SYSTEM MAINTENANCE
3.2112	ORDNANCE MAINTENANCE
3.212	MATERIAL
3.213	PERSONNEL SUPPORT
3.214	SITE MAINTENANCE
3.22	ASHORE FACILITIES
3.221	LABOR
3.2211	WEAPON SYSTEM MAINTENANCE
3.2212	ORDNANCE MAINTENANCE
3.222	MATERIAL
3.223	PERSONNEL SUPPORT
3.224	SITE MAINTENANCE
3.3	INSTALLATION SUPPORT
3.31	BASE OPERATING SUPPORT
3.32	REAL PROPERTY MAINTENANCE
3.33	PERSONNEL SUPPORT
3.4	DEPOT MAINTENANCE
3.41	SCHEDULED MAINTENANCE
3.42	UNSCHEDULED MAINTENANCE
3.43	MODERNIZATION
3.44	COMPONENT REPAIR
3.5	DEPOT SUPPLY
3.51	MATERIAL MANAGEMENT
3.52	TECHNICAL SUPPORT
3.6	SECOND DESTINATION TRANSPORTATION
3.61	SCHEDULED
3.62	UNSCHEDULED
3.7	PERSONNEL SUPPORT AND TRAINING
3.71	INDIVIDUAL TRAINING
3.72	HEALTH CARE
3.73	PERSONNEL ACTIVITIES
3.74	PERSONNEL SUPPORT
3.8	SUSTAINING INVESTMENTS
3.81	REPLENISHMENT SPARES
3.82	MODIFICATIONS
3.83	REPLENISHMENT SUPPORT EQUIPMENT
3.84	EXPENDABLE STORES
4.	ASSOCIATED SYSTEMS
4.1	INVESTMENT
4.11	MOBILE LOGISTICS SUPPORT FORCE
4.12	TENDERS AND REPAIR SHIPS
4.13	ASHORE IMA
4.2	OPERATING AND SUPPORT
4.21	MOBILE LOGISTICS SUPPORT FORCE
4.22	TENDERS AND REPAIR SHIPS
4.23	ASHORE IMA
4.24	EMBARKED SYSTEMS
5.	TERMINATION

are of equal importance. The Major System Model lists those elements which it feels are the major cost drivers for each cost element. These drivers are listed below:

1. Research and development

    engineering
    software
    documentation
    system test and evaluation

2. Investment

    production hardware
    peculiar support equipment
    initial spares and repair parts
    government furnished equipment and material
    operational sites
    maintenance facilities

3. Operating and Support

    crew
    material
    oragnizational/intermediate maintenance
    depot maintenance
    sustaining investments (replenishment spares and modifications)

4. Associated Systems

    investment

5. Termination

    termination

C.3 MANPOWER COSTING IN THE MAJOR WEAPONS SYSTEMS MODEL

The Cost Breakdown Structure for Major Weapon Systems provided in the Major System Model includes several explicit manpower categories. These categories are: investment training, operating crew, operating staff, other deployed manpower, O/I maintenance, ashore labor, depot maintenance (scheduled and unscheduled), and personnel support. In addition, there are many other cost categories which include manpower costs as subelements. For example, the main cost element of security costs is the cost of paying security personnel such as guards.

In keeping with its role as a costing guide, the cost equations for personnel wages and training merely indicate that there is a cost which must be determined by the analyst, but does not provide the analyst with techniques for estimating that cost. All training costs are direct throughputs. A generalization for the manpower cost equations presented in the Major System Model is the following:

$$\text{Wage costs} = \sum_{I=1}^{Y} \sum_{A=1}^{B} N_i(I,A) * P_i(A)$$

where I is the designator for a specific year in the system life cycle, Y is the total number of years in the life cycle, A is a designator for specific pay grade, and B is the number of different pay grades considered in the cost analysis. $N_i(I,A)$ is the number of type i personnel (i = operators, depot maintenance, etc.) of pay grade A used in year I of the system life cycle, and $P_i(A)$ is the annual billet cost for type i personnel of pay grade A.

This generalized formula for manpower costs is essentially correct as far as seeing a cost bucket which must be filled. However, as discussed in Volume I of the report, the process of arriving at values for each $N_i(I,A)$ is an extremely complicated one. In order for the Major Systems Model to be of value as a manpower tradeoff tool, it will be necessary to incorporate analytical methodologies for determining the values of $N_i(I,A)$. While the FLEX option makes this possible, the same drawbacks discussed at the conclusion of Appendix B pertain here.

APPENDIX D. SEAFIRE MODEL

D.1 SEAFIRE LIFE CYCLE COST MODEL

All of the other models reviewed in this study were developed as general-purpose structures. That is, considerable energy was devoted to an attempt to make each one suitable to a variety of equipments. The SEAFIRE Model, intended for use in the specific acquisition program of that name, is far simpler and more focussed as a consequence of this specificity.

While the review of other models is strictly pertinent only to each model covered, the SEAFIRE model is important as an example of a class of models. We refer to these as program office models. They are (sometimes) prepared by a program office for use with a specific acquisition and, as such, are intended for the design period of the WSAP. With this fact in mind, the review here is focussed more sharply on the qualities required of a cost model in that period. It must be sensitive to engineering variables, reflect support policy options which can still guide the design of components, be convenient to use and mask government policy options unrelated to design from the user. In addition, inter-temporal tradeoffs should be adequately portrayed and the use of throughputs minimized.

The SEAFIRE model was developed at the Naval Surface Weapons Laboratory, Dahlgren. The program office, also at Dahlgren, operates on behalf of the Naval Sea Systems Command.

This discussion deals only with the Operating and Support (O&S) section of the SEAFIRE Life Cycle Cost Model. There is no discussion of the other two sections of the model--Engineering Development and Pilot and Full Scale Production--because other than a learning curve adjustment, there is no mathematical structure associated with these elements.

The O&S section of the SEAFIRE model consists of eighteen equations which calculate costs for each year of the system's estimated twenty-year life cycle. These costs can then be adjusted by inflation factors provided by the Navy Program Office. No discounting formulation is available. Six of the eighteen cost equations deal with manpower costs, and will be discussed in detail below. We will deal here only with those elements of the remaining cost equations which have significant problems in their formulation. A complete listing of the cost categories of the SEAFIRE Cost Model is provided in Table D-1.

Space Cost

The SEAFIRE Model computes space costs for maintenance and inventory storage. The space requirements for these two categories are multiplied by the cost per space (square feet for maintenance and cubic feet for inventory storage). To compute space costs, the following parameters must be input to the model: the maintenance floor space requirements for ship, intermediate and depot level; the inventory allowance space for ship, intermediate and depot level; and the system stock space requirement. All of these important parameters--which can only be determined as the end result of cost/performance and LOR tradeoff analyses--must be

Table D-1. SEAFIRE Life Cycle Cost Model
Cost Breakdown Structure

I. Engineering Development and Pilot Production

II. Full-Scale Production

III. Operating and Support

1. Support and Test Equipment Maintenance
2. Operating Personnel Labor
3. Technical Data Management
4. Replacement Training
5. Space
6. Supply Support Management
7. Scheduled Equipment Overhaul
8. Preventative Maintenance Labor
9. O-Level Corrective Maintenance Labor
10. Maintenance Documentation
11. Preventative Maintenance Material
12. I-Level Corrective Maintenance Labor
13. Depot Level Corrective Maintenance Labor
14. I-Level Corrective Maintenance Parts
15. O-Level Corrective Maintenance Parts
16. Depot Level Corrective Maintenance Parts
17. Replenishment Inventory
18. Second Destination Transportation

calculated externally.

Supply Support Management

In calculating the cost of managing the inventory of sub-elements of SEAFIRE, the model takes the product of the number of new SEAFIRE parts in the National Stock Number (NSN) System, and the sum of operational, intermediate and depot sites, then multiplies by a field supply management cost standard. This is an error: the appropriate value is not the number of *new* SEAFIRE parts, but the *total* number of parts.

Replenishment Inventory

The replenishment inventory requirement for a unit is calculated by multiplying the expected number of failures of the unit by the sum of the scrap rates at the organizational, intermediate and depot levels. To get around this problem, the scrap rate for each level should be multiplied by the labor repair rate, which is the fraction of total failures repaired at the organizational, intermediate and depot levels, respectively.

D.2 MANPOWER COSTS IN THE SEAFIRE MODEL

The following manpower costs are included in the Operating and Support subroutine of the SEAFIRE Cost Model:

1. Operating personnel labor
2. Replacement training
3. Preventative maintenance labor
4. O-level corrective maintenance labor
5. I-level corrective maintenance labor
6. Depot level corrective maintenance labor

Each of the manpower cost categories will be reviewed in turn and what seem to be significant problems in their formulation will be noted as they arise.

Operating Personnel Labor

The equation for computing operating personnel labor is the following:

$$\begin{pmatrix}\text{annual}\\ \text{operator}\\ \text{labor}\end{pmatrix} = \begin{pmatrix}\text{\# of systems}\\ \text{operating}\\ \text{in year i}\end{pmatrix} \begin{pmatrix}\text{\# operators}\\ \text{per}\\ \text{system}\end{pmatrix} \begin{pmatrix}\text{annual}\\ \text{operator}\\ \text{labor rate}\end{pmatrix}$$

The formulation of the equation is doubly misleading. First, there is no method available to distinguish between utilizing existing operators (a likely option for SEAFIRE) and adding new personnel to the ship on which SEAFIRE will be deployed. The second problem is more a potential for misunderstanding than a conceptual error. If it requires one man to operate SEAFIRE, then the value for number of operators per system is not necessarily 1, but rather the number of operators assigned to each ship based on the operational profile of SEAFIRE.

Replacement Training

The SEAFIRE LCC Model computes attrition related training costs at the operational, intermediate, and depot level. The formula for operational level training is:

$$\text{Training} = N * TRN * TOR * (Op + MTN)$$

where N is the number of systems, TRN the O-level training cost, TOR the O-level turnover rate, Op is the number of operators per system, and MTN is the number of O-level maintenance personnel.

The input variable Op is the same one that is used in calculating operator wage costs. This leads to incorrect values, because the number of men operating the system (for direct compensation cost calculation) is not equal to the number of men who will require training. To get around this problem, the input variable Op should be divided into two new variables, the labor requirement for operation on each ship and the number of men per ship to receive SEAFIRE training.

The SEAFIRE LCC model provides a default value for O-level training cost at $2,600 per man. This value is not an unreasonable estimate of the average cost of O-level training if one assumes that there are going to be four operators trained for every maintenance technician or that the training course cost is $1,000 and $8,000, respectively. Unfortunately, using a single average value for both operator and maintenance training cost makes it impossible to use the model to conduct such hardware/manpower tradeoffs as investing in extensive built-in test equipment and module discard technology as a way of reducing maintenance training costs.

The number of maintenance personnel per ship need not be an input value which must be determined externally to the model. Its value can--and should--be calculated within the model from the preventative and corrective maintenance manhour requirements of SEAFIRE.

I-level and depot training costs are calculated using the same formula as O-level. The default values for I-level and depot training costs are \$2,600 and \$3,500, respectively. In order for these training costs, which are exclusively concerned with maintenance, to be consistent with the assumptions used to derive the average value of \$2,600 for operational level training they each should have been in excess of \$8,000. That they are not invalidates this part of the training cost computation.

Preventative Maintenance Labor

The formula for preventative maintenance labor is straightforward:

$$\begin{pmatrix}\text{preventative}\\ \text{maintenance}\end{pmatrix} = \sum_{i=0,I,\text{depot}} \text{OHR}/\text{MTBPMA}_i \, \text{MTTPMA}_i \, \text{LRATE}_i$$

where OHR is system annual operating hours, MTBPMA_i is mean time between preventative maintenance actions at maintenance level i, MTTPMA_i is mean time to perform preventative maintenance action at maintenance level i, and LRATE_i is the hourly wage rate at maintenance level i.

Corrective Maintenance Labor

The corrective maintenance labor cost is computed separately for i-0 level, i=I level, and i=depot level maintenance activity using the following formula:

$$\begin{pmatrix}\text{i-level}\\ \text{corrective}\\ \text{maintenance}\end{pmatrix} = (1 - SRATE_i)\ N * OHR/MTBF * MTTR_i * LRATE_i$$
$$* RRATE_i * FRR$$

where $SRATE_i$ is the i-level scrap rate, MTBF is mean time between failures, $MTTR_i$ is i-level mean time to repair, $RRATE_i$ is the i-level repair rate (fraction of failures requiring i-level labor), and FRR is the false removal rate.

The logic behind this equation is the following. N * OHR/MTBF tells you how many system failures can be expected each year. Multiplying this by FRR tells you how many removals there will be. The $RRATE_i$'s are the level of repair switches. For example, ($RRATE_0$ = 0, $RRATE_I$ = 0, $RRATE_{depot}$ =1) signals depot repair ($RRATE_0$ = 1, $RRATE_I$ = 0, $RRATE_{depot}$ = 0) signals local repair $RRATE_i$ = 0 for i=0,I,depot) signals discard, and so on. Therefore, multiplying by $RRATE_i$ yields the number of repair demands at the i-level maintenance activity per year. Items which are scrapped do not undergo repair, which accounts for the (1 -$SRATE_i$) factor. $MTTR_i$ * $LRATE_i$ is the labor cost per repair.

This formula, includes the labor cost *only* for repair of a failed item. The labor cost of fault isolation, removal and replacement of the item at the O-level and the labor cost incurred at all levels in determining

that an item cannot be repaired is not included in the model. This means, for example, that if the SEAFIRE model is run for a unit which is coded discard, the result will be that there will be no corrective maintenance labor costs. This error was also discussed with reference to the 1390B Ordnance Model in Appendix A, where it also occurs.

A review, by its nature, concentrates on what is wrong, not right. The case of the SEAFIRE model should not be misunderstood: not withstanding the errors discussed above, the coverage of this model is more extensive than most. In particular, recognition of operator costs--both for training and compensation marks the model as more comprehensive than most program office models we have seen--from *any* of the military departments.

This comment unfortunately fails to overshadow the shortcomings of the model: its insensitivity to design elements which can only be manipulated easily at this stage of the WSAP. This and other difficulties apparently arise from two things: lack of solid guidelines and the temptation to solve all cost analytic problems with a single model. With appropriate guidelines, model formulations could have been enhanced greatly. The same would be true had the attempt *not* been made to fit an analytic cost model into a rigid budget/accounting framework.

Final Report

ASC R-119

NAVAL MANPOWER COSTS AND COST MODELS: AN EVALUATIVE STUDY

August 1978

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PREFACE

The study reported herein was undertaken as part of the Manpower/Hardware Life Cycle Cost Analysis Study, an element in the CNO Studies and Analysis Program for Fiscal 1977. It was conducted by Administrative Sciences Corporation under Contract No. N00014-77-C-0811 with the Office of Naval Research. Subcontracting support was provided by J. Watson Noah Associates, Inc. The findings and recommendations contained in this document are those of the research organizations who performed the work, and do not necessarily reflect the views of the Department of the Navy.

EXECUTIVE SUMMARY

The objective of this study was twofold: (1) to critically analyze the Bureau of Personnel's Billet Cost Model (BCM); and (2) to evaluate other (less detailed) sources of Naval manpower costs. Part of a larger effort called the Manpower/Hardware Life Cycle Cost Analysis Study, this work was motivated by a desire on the part of the Navy to improve the analytic tools available with which "....to assess manpower and training requirements in terms of their affordability and availability during weapon system development."

Findings

The concept of a "billet cost model" is sound and the need for such a model undeniable. The present BCM, however, was found to exhibit certain deficiencies for which remedies are fairly straightforward. The deficiencies relate more to the model's input data than its estimation algorithms. Also, potential users of the BCM are handicapped by a lack of thorough and timely documentation.

Other sources of Naval manpower costs; i.e., Composite Standard Rates, the Navy Resource Model and OASD (Comptroller) reports, were found in general to be deficient for use where manpower requirements are defined in less detail than rating and grade. Difficulties include omitted or improperly treated cost elements - especially training and retirement- as well as the inability of the sources to differentiate between occupational categories and/or skill levels of manpower. Generalization of billet costs across ratings and grades offers the most promise.

Recommendations

Specific recommendations were provided for remedying the technical problems noted in the BCM, and for generalizing those results along the lines suggested above. Further recommendations were offered concerning both the packaging and content of billet cost estimates. In particular, it was recommended that the Bureau of Personnel publish, on an official and annual basis, a Billet Cost Report.

The report would consist of, first, text which thoroughly explains how the estimates were developed, and also explains which estimates are appropriate for different uses. The second section would include two sets of marginal cost estimates, one by rating and grade and the other generalized across ratings and grades. The final section would consist of average cost estimates, of which there would similarly be two sets. These would be explained to be applicable to decision analyses involving large increments or decrements of manpower. Throughout, all non-Navy costs would be made sufficiently visible so that total billet costs, net of those amounts, would be readily available for use in analyses which are administratively constrained to include only Navy-funded costs. The overall goal of the report would be to serve a very broad spectrum of manpower costing needs throughout the Navy, but to do so in such a way that no set of needs is sacrificed or compromised in order to satisfy another.

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PART I:

BILLET COST MODEL

I.1. INTRODUCTION

The Statement of Work from which this study emanated required that the Billet Cost Model (BCM) be analyzed with respect to "the degree to which (it) reflects costs that are relevant to economic decisions (i.e., relevant to choices of alternative allocations of resources.)"[1] More specific requirements included:

(1) An analysis of the degree to which the BCM reflects costs which vary directly with manpower changes and the degree to which it reflects costs that are fixed in the short run. The ability of the model to generate marginal costs should be examined.

(2) An analysis of samples of the data underlying the BCM with the criterion of relevance to economic decisions.

(3) An analysis of the current method of allocating training costs in the BCM.

(4) A statistical analysis of the methodology of computing continuation rates in the model.

(5) An examination of the methodology for imputing the economic cost of expected retirement liabilities.

(6) Analysis of the ability of the model to reflect costs by annual program element.

To a considerable extent, the motivation for this study was the same as for the recent Military Manpower Versus Hardware Procurement Study (HARDMAN); namely:

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[1]Attachment Number I to RFP No. N0014-77-R-0023, 15 August 1977, and incorporated as Attachment Number I to Contract No. N00014-77-C-0811, 30 September 1977.

> "With the recent dramatic increases in manpower costs within the Department of Defense and the prospective reductions in the size of the national labor pool, there has been a new impetus on the part of policymakers to assess manpower and training requirements in terms of their affordability and availability during weapon system development."[2]

In fact, the Manpower/Hardware Life Cycle Cost Analysis Study, of which this effort is part, resulted from a HARDMAN recommendation. This background is important because it has definite implications with respect to uses of the Billet Cost Model. The analysis of any cost model must ultimately be from the perspective of how well it serves its intended uses. To elaborate, model "A" may be entirely adequate for Navy programming needs, while model "B" may satisfy budgeting requirements. However, neither "A" nor "B" may be well suited for use in trade-off analyses during weapon system development. It is this final category of use which requires primary emphasis in the present study.

Organization of PART I

Following this Introduction, Section I.2 presents a discussion of issues, principles and criteria pertinent to the BCM analysis. That is followed in Section I.3 by an overview of the billet model. Section I.4 contains a detailed description and analysis of the model on an element-by-element basis.

Section I.5 examines several aspects of the model which cannot be

[2] Military Manpower Versus Hardware Procurement Study (HARDMAN), Final Report, 26 October 1977, p. vi.

dealt with conveniently in the discussion of individual cost elements. Those include: (1) computation and use of "continuance rates"; (2) development of billet costs by grade; (3) generalization of billet costs across ratings and grades; (4) effects of manpower supply shortages; (5) factors bearing on (and inhibiting) development of officer billet costs; and (6) the model's existing and required documentation. The purpose of Section I.6., Remedial Actions Recommended, is to collect in one central place the various additions, deletions and modifications of the Billet Cost Model that have been proposed in the foregoing sections.

I.2. ANALYTIC PRINCIPLES, ISSUES AND CRITERIA

Before initiating the detailed description and analysis of the BCM, the following discussion of principles, issues and criteria is provided to establish the conceptual framework from which the analysis will proceed.

I.2.1. Hierarchical Decision Levels

A well-established principle of defense cost analysis is that proper identification and estimation of costs is dependent on the hierarchical level at which decisions are made.[1] The position taken in this study (and by the BCM) is that the appropriate decision level is that of the Federal Government. Stated differently, the attempt is to capture all costs which vary with Navy manpower utilization, regardless of which governmental department funds the costs, and regardless also of whether the costs are explicit or implicit. A practical benefit of this approach is that selected cost elements and their associated estimates can always be eliminated from a model's output if a lower decision level is appropriate.

I.2.2. Relevance of Future Costs

Another well-established principle is that only future costs are relevant for decision purposes. The irrelevance of "sunk" costs is strongly emphasized in the literature. However, that is not the context in which the future aspects of costs are important in this study. The only way future

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[1]This point is developed in Gene H. Fisher, Cost Considerations in Systems Analysis, (New York: American Elsevier, 1971), pp. 45-47.

costs can be estimated is on the basis of present information and empirical data. Part of that information may include explicit insights into how costs will change in the future. (The notion of "change" here means something other than projected price level increases.) In such cases it is necessary that empirical data be used carefully - and conceivably not at all - for estimating future costs. This principle has practical application in at least two situations. First is where institutional changes are taking place. An example is the amount and distribution of bonuses paid for reenlistment. Use of past reenlistment bonus cost data without reference to the on-going changes would result in poor estimates. A second example is where certain training profiles presently in existence must be altered significantly to support an advanced system's requirements. Again, extrapolation based on present costs may not be appropriate. To some extent these are situations that can be dealt with by proper monitoring and model updating, but they also serve to illustrate: (1) the difficulty of a single set of cost estimates serving all needs; and (2) the constant obligation a user has to understand how a model's estimates are generated, and to question their adequacy in any specific application.

I.2.3. Short-Run vs. Long-Run

Measurement of the cost consequences of alternative courses of action (selection from which is the essence of decision analysis) is also dependent on the time horizon of the actions in question. This is recognized in economic theory where a distinction is made between the short-run and the long-run. In the former, some inputs (and hence some costs) are con-

sidered fixed and thus irrelevant to actions contemplated over a correspondingly short period of time. In the long-run, all resources and costs are considered variable. The significance of this for Naval manpower costing is as follows. Assume that a decision is being considered to increase present levels of recruiting and subsequent training. (Whether in selected ratings or across-the-board is unimportant for the example.) If this were viewed as a short-run action - in response, say, to increased international tensions - cost estimates would almost certainly be lower than if the new levels were perceived as permanent. The reason is that recruiters, examiners, instructors, etc. would be assigned higher-than-normal work loads, while housing and other facilities would be utilized at higher-than-recommended levels. Cost estimates of the long-run effects of such a change would, of course, provide for additional support staff and facilities, and therefore be higher.[2] The position taken in this study is that the BCM should be analyzed with respect to its relevance to long-run economic decisions.

I.2.4. Marginal vs. Average Costs

A central issue in the analysis of any cost model is the relationship between marginal and average costs. In principle, the concepts are quite straightforward. Marginal cost is the cost of adding one unit to some existing quantity of units. Average cost is simply total cost distributed evenly

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[2]Economic theory would suggest an opposite result from this. Theory treats the additional short-run (variable) inputs as being more costly and/or capable of less efficient use because of limitations inherent in fixed inputs. It does not take into account the natural - although temporary - "stretchability" in an institution such as the U.S. Navy, which in practical cost terms would undoubtedly offset the theoretical considerations.

among all units involved. Inasmuch as decisions typically center on changing from one position to another, it is marginal costs that have analytic relevance, not average costs. The problem with that, however, is frequently the only empirical cost data available relate to averages. William Baumol expresses the matter succinctly:

> "It is clear.....that whenever there is a difference between average and marginal data, it is the latter which must be given prior consideration in an optimization problem. Unfortunately,....marginal data may be difficult and in some cases, for practical purposes, impossible to come by. It is therefore sometimes necessary to make do with average figures. For this purpose one must understand the relationship between average and marginal figures to recognize the circumstances under which the one can be expected to provide a reasonably good approximation to the other, and to determine, when this is not the case, what sort of rough adjustments in the average data can be made to bring them closer to the unknown marginal figures."[3]

In the case of manpower costs, the situation in general is not bad. First, many cost elements such as pay and allowances are incurred on a per-individual basis, and marginal data are therefore readily available. Second, even when only averages are reported (PCS costs, for example), their nature is such that they tend to be highly and uniformly divisible rather than "lumpy." For certain other costs, however, such as training where averages reflect allocations of facility and administrative overhead, adjustments may be called for as Baumol suggests. These considerations will arise frequently in the subsequent discussion and analysis of the Billet Cost Model.

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[3]Baumol, William J., Economic Theory and Operations Analysis, (Englewood Cliffs, N.J.: Prentice Hall, 1965), pp. 35-36.

I.2.5. Variability of Costs

Another issue of fundamental importance is raised by the following question: What, exactly, should the BCM be estimating? A portion of the answer has been supplied by the preceding discussion; i.e., future costs of a long-run nature incurred by the U.S. Government as a result of a marginal change to a given billet structure. What remains to be defined precisely is the nature of a "billet cost." At the heart of the issue is the fact that the cost of services associated with the filling of a given billet is, by definition, a variable rather than a single datum.[4] It is the sum of several elements, few if any of which admit of exact measurement, and most of which may assume any of several values even in the context of marginal analysis. Consider, for example, one element of billet cost: base pay. Even when a billet requirement is defined by rating and grade, base pay is not uniquely determined. It will vary - in some cases widely - as a function of LOS. One must recognize that when an individual cost element or a total billet cost is reported as a single number, that value is simply representative of several possible values; i.e., it is (at least presumably) a "best estimate."[5] Cost variables are often best represented by their means (expected values), both because the mean is frequently very close to the single value or set of values most likely to occur, and because its use typically avoids "bias"; i.e., consistent under- or overestimation.

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[4]In principle it is a stochastic, or random, variable; i.e., one that may assume different values in accordance with a probability distribution.

[5]In statistical theory, the question of what constitutes an optimal estimate is a matter of considerable importance and complexity.

However, in some situations the mean is little more than a statistical artifact, bearing virtually no relationship to costs that are actually incurred. In those cases an alternative to the mean should be sought.

I.2.6. Unique Nature of Military Manpower

The final, and by far the most difficult, conceptual issue concerns the very nature of military manpower. The training and experience necessary to fill a military billet (at anything other than the entry level) cannot be directly procured. It must be "nurtured," in some cases over considerable time and - some would argue - at considerable expense. The basis of the "considerable expense" argument is that the true cost of, say, an additional Aviation Boatswain's Mate, E-8, is not simply the sum of the BCM's cost elements for that rating and grade, but also includes the (properly allocated) costs of far-more-than-one additional personnel who must enter and ultimately leave the nuturing process in order for the additional billet-year of service to be continually supplied. This argument has merit. Granting the crucial assumption on which it rests, it is absolutely valid. The assumption is that no requirement exists for, and hence no productive or cost-offsetting use can be made of, any manpower services generated by that process other than those of the target billet. In the judgment of the analysts conducting this study, that assumption is invalid. First, it is unreasonable to assume on a priori grounds that personnel who have demonstrated sufficient mental and physical abilities to satisfy enlistment and training standards can be usefully assigned to only one billet or type of billet.

Moreover, there is abundant empirical evidence to the contrary. It is therefore concluded that, given proper conceptual and empirical handling of the model's cost elements, the sum of those elements does indeed represent the full marginal cost of an additional billet. It should be acknowledged, however, that proper handling of the costs requires - among other things - recognition of: (1) the existence of a training "pipeline"; and (2) that the cost of the pipeline is a proper charge against operational billets. This topic, and several of its derivatives, will arise frequently throughout the remainder of the report.

I.3. OVERVIEW OF THE BILLET COST MODEL[1]

The Billet Cost Model conceptualizes Naval manpower as being defined by two companion matrices:[2]

(A)

	Length of Service
Rating	1 2 3..................30
AB	
.	
.	
.	
.	
.	
YN	

(B)

	Grade
Rating	E-1 E-2...............E-9
AB	
.	
.	
.	
.	
.	
YN	

Actually, each of the above comes in pairs. There is a cost version and an inventory version of both (A) and (B), although the inventory matrices do not appear in the model's output. Nevertheless, it is noteworthy that total annual cost for any given overall billet structure may be estimated, at least in principle, by summing the products of corresponding cells in a cost/inventory matrix pair.

A considerable amount of input data and computations are required to generate entries in the cost matrices. Much of the discussion in Section I.4

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[1]Other references for the BCM are LCDR James L. Fitzgerald, Manpower Cost Study, January 1969; B.K. Dynamics, Inc., Billet Cost Model Users Manual, September 1970, and Billet Cost Model Users Manual, TR-3-227, November 1976.

[2]This description differs from that given in the above references where considerable emphasis is placed on the model's "pipeline" aspects. The effort here and in Section I.4 is to describe the model in terms of the output a potential user will see, and to explain how that output is generated.

- and in fact much of this study - centers on the generation of those numbers. However, as an introduction to that discussion, it is useful to point out that matrix (B) essentially depends on (A). That is, costs by length of service (LOS) are estimated first, and grade costs are then drawn from that matrix on the basis of median service length. For example, if it is known (via input) that median service length of an E-6 Yeoman (YN) is 14.7 years, costs for LOS 15 are assigned to grade 6.

Also by way of introduction, all of the description above has been in terms of enlisted ratings and grades. The BCM essentially makes no distinction between officers and enlisted insofar as cost elements and computations are concerned. It is therefore possible to describe the model and evaluate it as a tool for use in economic decision-making while focusing on enlisted resources alone. Naturally, a different body of input data is required to generate officer billet cost estimates, but for the past several years that data has not been assembled. Consequently the empirical analysis in Section I.4. relates only to enlisted manpower, which constitute some 85% of the Navy's authorized strength. The subject of officer billet costs is examined in Section I.5.5.

I.3.1. Enlisted Ratings

Billet costs for each of the following enlisted ratings presently appear in the model's output. Note that each rating carries a two-character identifier; e.g., AB - Aviation Boatswain's Mate, and that some are further divided into three-character specialties; e.g., ABE - Launch & Recovery Equipments. The BCM does not generate cost estimates at the Navy Enlisted Classification (NEC) Code level.

Rating Identifier		Title
(AB)		AVIATION BOATSWAIN'S MATE (Ground Support)
	(ABE)	- LAUNCH & RECOVERY EQUIPMENTS
	(ABF)	- FUELS
	(ABH)	- AIRCRAFT HANDLING
(AC)		AIR CONTROLMAN (Air Traffic)
(AD)		AVIATION MACHINIST'S MATE
(AE)		AVIATION ELECTRICIAN'S MATE
(AG)		AEROGRAPHER'S MATE (Meteorology)
(AK)		AVIATION STOREKEEPER (Air Logistics)
(AM)		AVIATION STRUCTURAL MECHANIC
	(AME)	- SAFETY EQUIPMENTS
	(AMH)	- HYDRAULICS
	(AMS)	- STRUCTURES
(AO)		AVIATION ORDNANCEMAN
(AQ)		AVIATION FIRE CONTROL TECHNICIAN (Air Ops)
(AS)		AVIATION SUPPORT EQUIPMENTS TECHNICIAN
	(ASE)	- ELECTRICAL
	(ASH)	- HYDRAULICS & STRUCTURES
	(ASM)	- MECHANICAL
(AT)		AVIATION ELECTRONICS TECHNICIAN
(AW)		AVIATION ASW OPERATOR (Anti-Sub Weps/Air Sensor Ops)
(AX)		AVIATION ASW TECHNICIAN (Anti-Sub Weapons)
(AZ)		AVIATION MAINTENANCE ADMINISTRATIONMAN (Tech Librarian)
(BM)		BOATSWAIN'S MATE
(BT)		BOILER TECHNICIAN (Tender & Marine Engineer) (BR)
(BU)		BUILDER
(CE)		CONSTRUCTION ELECTRICIAN
(CM)		CONSTRUCTION MECHANIC
(CT)		CRYPTOLOGIC TECHNICIAN
	(CTA)	- ADMINISTRATION & INTELLIGENCE
	(CTI)	- INTERPRETATION & LINGUISTICS
	(CTM)	- MAINTENANCE & REPAIR
	(CTO)	- COMMUNICATIONS & COMM SECURITY
	(CTR)	- COLLECTION & RADIO/TELECOMMUNICATIONS
	(CTT)	- TECHNICAL & ELECTRONIC INTELLIGENCE
(DK)		DISBURSING CLERK (Paymaster & Salaries)
(DM)		ILLUSTRATOR DRAFTSMAN (Graphic Arts)
(DP)		DATA PROCESSING TECHNICIAN (Computer Operations)
(DS)		DATA SYSTEMS TECHNICIAN (Computer Programming/Repair)
(DT)		DENTAL TECHNICIAN
(EA)		ENGINEERING AID (Orthographic & Isometric Drawing)
(EM)		ELECTRICIANS MATE (Wiring & Repair)
(EN)		ENGINEMAN (Marine Engineering)
(EO)		EQUIPMENT OPERATOR (Earth Moving Machines, etc.)
(ET)		ELECTRONICS TECHNICIAN
	(ETN)	- NAVIGATION & COMMUNICATIONS (Repair & Maint.)
	(ETR)	- RADAR (Equipments Maintenance)

Rating Identifier		Title
(EW)		ELECTRONICS WARFARE TECHNICIAN (Ship Sensor Ops)
(FT)		FIRE CONTROL TECHNICIAN (Ship Weapons Control)
	(FTB)	- (FLEET) BALLISTIC MISSILE SYSTEMS
	(FTG)	- (NAVAL) GUNFIRE CONTROL SYSTEMS
	(FTM)	- (GUIDED) MISSILE WEAPONS CONTROL SYSTEMS
(GM)		GUNNER'S MATE (Ship Ordnance & Maintenance)
	(GMG)	- (NAVAL) GUNS MAINTENANCEMAN
	(GMM)	- (GUIDED) MISSILE LAUNCHING SYSTEMS
	(GMT)	- TECHNICIAN & SPECIALISTS
(HM)		HOSPITAL CORPSMAN (Health Care)
(HT)		HULL MAINTENANCE TECHNICIAN (Ship Maintenance) (DC/SF)
(IC)		INTERIOR COMMUNICATIONS ELECTRICIAN
(IM)		INSTRUMENTMAN (Metal Fabrication & Schematics)
(IS)		INTELLIGENCE SPECIALIST (PT) (Photo-Interpretion)
(JO)		JOURNALIST (Media)
(LI)		LITHOGRAPHER (Printing & Rotographics)
(LN)		LEGALMAN (Law & Naval Justice)
(MA)		MASTER-AT-ARMS (Law Enforcement)
(ML)		MOLDER (Construction of Molds & Castings)
(MM)		MACHINIST'S MATE
(MN)		MINEMAN (Water Mine Ordnance & Maintenance)
(MR)		MACHINERY REPAIRMAN
(MS)		MESS MANAGEMENT SPECIALIST (CS/SD) (Commissary/Food Prep)
(MT)		MISSILE TECHNICIAN
(MU)		MUSICIAN
(NC)		NAVY COUNSELOR (CAREER COUNSELOR)
(OM)		OPTICALMAN (Precision Lens & Metal Grinding)
(OS)		OPERATIONS SPECIALIST (Radar/Ship Ops/Maneuvering/RD)
(OT)		OCEAN SYSTEMS TECHNICIAN (Sensor Ops/SUBELINT/STO)
(PC)		POSTAL CLERK (Mail Handling/TE)
(PH)		PHOTOGRAPHER'S MATE
(PM)		PATTERNMAKER (Fabrication of Plates & Patterns)
(PN)		PERSONNELMAN (Personnel & Record Administration)
(PR)		AIRCREW SURVIVAL EQUIPMENTMAN (PARACHUTE RIGGER)
(QM)		QUARTERMASTER (Navigator & Ship Control)
(RM)		RADIOMAN (Communications & Teletype Message Traffic)
(SH)		SHIP'S SERVICEMAN (Barber/Tailor/Store/Laundry/Clerk)
(SK)		STOREKEEPER (Logistics/Stores/Supplies/Food Stuffs)
(SM)		SIGNALMAN (Semaphoric (Flag/Light) Communications)
(ST)		SONAR TECHNICIAN (Acoustical & Hydrophonic)
	(STG)	- UNDERWATER FIRE CONTROL SYSTEMS (From SURFACE)
	(STS)	- SUBMARINE FIRE CONTROL SYSTEMS (SUBSURFACE)
(SW)		STEELWORKER (Cut/Form/Place/Tie Metal Materials)
(TD)		TRADEVMAN (Simulators & Training Devices Sys Support)
(TM)		TORPEDOMAN'S MATE
(UT)		UTILITIESMAN (Installation of Water/Heat/Refrig Plants)
(YN)		YEOMAN (Administration/Clerical/Office Management)

The above represent all but seven ratings in the total inventory of ratings.[3]

Those omitted from the model are:

Rating Identifier	Title
(AF)	AIRCRAFT MAINTENANCEMAN
(AV)	AVIONICS TECHNICIAN
(CU)	MASTER CONSTRUCTIONMAN
(DN)	DENTALMAN
(EQ)	EQUIPMENTSMAN (EQUIPMENT MANAGEMENT)
(HN)	HOSPITALMAN
(PI)	PRECISION INSTRUMENTMAN (Metal Fabrication Management)

I.3.2. Cost Elements

The following thirteen cost elements appear for each rating, by LOS and by grade, in the Billet Cost Model:[4]

- Base Pay
- Hazard Pay
- FICA
- Constant Cost/Grade
- Proficiency Pay
- Constant Cost/Year
- School Cost
- Transport Cost
- Reenlistment & Settlement Cost
- Retirement Cost
- Total Cost (sum of above)
- Down Cost
- Billet Cost (sum of Total Cost and Down Cost)

[3]Reference CNO letter of 23 December 1977, Subj.: Enlisted Grade Guide.

[4]In a recent execution of the BCM (3 April 1978), the titles of certain of the cost elements had changed. However, since there appears to have been no formal decision to change the elements, and since the data reported under the new titles are consistent with the old, the above elements are considered for the purposes of this report as being official.

I.4. COST ELEMENT DESCRIPTION AND ANALYSIS

The general approach followed in this section is, for each cost element, to first describe the model's computational (estimation) procedures, and to then explain any modifications considered appropriate. Where ambiguities exist with respect to definition or coverage, they will be clarified. At the conclusion of the section a discussion and justification will be provided regarding certain elements considered to be necessary additions to the model.

I.4.1 Base Pay

Estimation Procedure - Base pay costs are computed first for the LOS matrix by combining: (1) an input table of statutory base pay for military personnel (by grade and LOS); and (2) a rating-specific input vector of mean time to advance (MTA) to grades 2 through 9. If, for example, the MTA to E-5 in a given rating is 4.3 years, base pay for year 5 is computed as the following weighted average:

.3(base pay for E-4, year 5) + .7(base pay for E-5, year 5)

Then, if MTA to E-6 is 10.6 years, base pay for years 6 through 10 is simply read from the table. In other words, those years are considered to be strictly "E-6" years. As previously mentioned, costs by grade are selected from the LOS matrix on the basis of median service length in grade. This statement applies equally to each of the remaining elements.

Analysis - There is no question as to the relevance of base pay, but the BCM's computation procedures require modification. First, for LOS cost, the present procedure can lead to severe distortions, particularly for higher LOS's. As a specific example, consider the Aviation Technician rating for LOS 21. MTA to E-9 being 19.4 years, base pay for LOS 21 is read from the E-9 line of the table as $14,124.[1] However, present (end-FY77) inventory data show the actual AT grade distribution for LOS 21 to be:

Grade:	E-9	E-8	E-7	E-6	E-5
Number:	18	32	49	20	1
Base Pay:	$14,124	$12,384	$10,932	$9,612	$8,160

Combining each component of the distribution with its corresponding pay rate results in a weighted-average base pay of $11,556, which seems clearly more representative of the actual LOS than $14,124, and is some 18% lower. It can be argued, of course, that present inventories may be different than those of a planned future force. Counter-arguments to that are: (1) present inventory data are used elsewhere in the model; and (2) use of almost any reasonable inventory would be preferable to the implicit assumptions and rigidities associated with use of the MTA vector.

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[1]Unless otherwise noted, all BCM data reported here were obtained from an FY77 run of the model dated 13 September 1977. Those data were selected because they were available at the beginning of the study, and becaus they were on a consistent fiscal year basis with the alternative sources of manpower costs examined in Part II.

As for base pay by grade, the difficulty stems from the model's procedure of generating grade costs by transferring a number from the LOS matrix on the basis of median service length in grade (MSL). As an example, consider the E-9 grade in the ET rating. MSL is 19.6, meaning that LOS 20 base pay ($13,860) is assigned to the grade. Based on the FY77 inventory data below,

LOS:	13-14	15-16	17-18	19-20	21-22	23-26	27-30
Number:	3	12	37	51	26	8	22
Base Pay:	$12,960	$13,248	$13,560	$13,860	$14,124	$14,868	$16,308

the grade's weighted average is $14,160. Here the model's estimate is lower, although by considerably less than the 18% difference found with the LOS cost example. The reason the two estimates are close is because the LOS distribution is relatively symmetric. If it were highly skewed, the difference would be much greater. In those cases, and also where there is considerable year-to-year variation in cost, the MSL procedure can produce unrepresentative cost estimates. Inasmuch as inventory tapes are readily available, generation of the recommended estimates (weighted-averages) for all ratings would seem to be quite straightforward.

I.4.2 Hazard Pay

Estimation Procedure - Hazard Pay, also identified as Incentive Pay, is computed by combining: (1) an input table of hazard pay by grade and LOS; (2) a rating-specific input vector of fraction of billets authorized to receive hazard pay in each pay grade; and (3) the MTA input vector described

above. As an example computation, assume the following data:

	MTA	Fraction Receiving Hazard Pay	Hazard Pay (year 5)
E-4	Not req'd.	.075	$840
E-5	4.8	.236	960

Hazard pay for year 5 would then be computed as:

$$.8(.075)840 + .2(.236)960 = \$96$$

If MTA to E-6 is 10.6 years, hazard pay for years 6 through 10 would be read directly from the table and multiplied by the fraction of E-5's receiving the pay.

Analysis - There is no question as to the general relevance of hazard pay, but the computational procedure employed is not altogether adequate. The use of expected values such as $96 in the example above leads to precisely the problem discussed in Section I.2.4. In the context of marginal costing, a billet in question is either eligible or not eligible for hazard pay. In other words, the correct estimate is either zero or something on the order of $900 (remaining in the range of the example.) Virtually no meaning attaches to the expected value in this case.

Perhaps the best approach for incorporating this change into the model would be, in the summary of costs by grade, to compute two costs for all ratings that are potentially eligible for hazard pay (approximately 40% of the total). In one the cost would be included and in the other it would be omitted. Special treatment of this kind seems warranted since hazard pay is

the only cost element that is both dichotomous in nature and billet-specific. Note that the recommendation is for this to be done only for costs by grade. Since billets are officially identified by rating and grade (and not by LOS), it is the position of this study that LOS costs are important only to the extent they are useful in computing costs by grade. In this instance, and in many others, they are not.

I.4.3. FICA

Estimation Procedure - FICA costs (borne by the Government) are computed by multiplying an input (or block data) FICA rate by base pay, not to exceed the statutory ceiling amount which is also a pre-set value.

Analysis - The analysis of FICA costs is not as straightforward as it might appear. Under the Social Security Amendments of 1977, an individual who remains in the Navy for an extended period of time will make FICA employee contributions which, under any reasonable set of assumptions, will exceed his actuarially expected benefits. Thus the Government incurs no present or future cost liability in this connection, and its "contribution" as employer is in reality a transfer payment used to finance other current Social Security obligations.[2] This would suggest then that for certain uses of billet costs - trade-offs between billets being the clearest example - FICA costs are not relevant and should be excluded. However, for other applications such as manpower-hardware tradeoffs, which may be more important, the FICA element should probably be retained because it is embedded

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[2]The authors wish to acknowledge that this was first brought to their attention by CDR Rolf Clark, USN.

throughout the hardware costs and, as a practical matter, is very difficult to extract. Considerations such as this underscore the importance of providing written guidance, not just computer printout, to the potential users of a cost model.

I.4.4. Constant Cost/Grade

Estimation Procedure - Constant Cost/Grade represents a collection of cost elements which are thought to vary with grade rather than with occupational skill or length of service. Estimates of the individual components are developed outside the model, principally from budget data. They are then input as totals per grade. The elements included, their appropriation categories and costs for selected grades, are shown below:[3]

Element	Costs E-7	E-3	E-1	Appropriation
Sea & Foreign Duty Pay	$ 103	$ 53	$ 11	MPN
Family Separation Allow.	25	0	0	MPN
Overseas Station Allow.	61	0	0	MPN
Basic Allow. for Qtrs.	1,787	553	227	MPN
Govt. Furnish. Qtrs. Imputed	801	757	821	MILCON
Unemployment Ins.	15	224	540	Non-DOD (Dept. of Labor)
Medical/CHAMPUS	1,190	400	334	O&MN, DOD
Commissary	150	44	42	O&MN, MILCON
PCS	671	28	544	MPN
	$4,803	$2,060	$2,520	

[3]This breakout is not elsewhere documented and was obtained informally from B.K. Dynamics, Inc. Although it is not accurate to the dollar, the accuracy is more than sufficient for the purposes of this analysis.

Analysis - Virtually all comprehensive analyses of Naval manpower costs include some measure of each of the above. The attempt to allocate such costs as Government Furnished Quarters and Medical/CHAMPUS by grade is in part a subjective, and in part an arbitrary, exercise. The best that can be done to test the reasonableness and accuracy of the BCM's estimates is to compare them with estimates from other sources, and to examine their consistency with budget activity totals. Such tests were conducted, and the outcome revealed no major problems. However, there are two concerns associated with Constant Cost/Grade which will be discussed below in order of ascending importance.

First, there is a problem with the Billet Cost Model which is not unique to Constant Cost/Grade. The problem is one of failure to capitalize, i.e., to treat as an investment which has value over time, costs associated with the E-1 grade. As reflected in the numbers shown above, the E-1 constant cost is some 25% higher than that of the E-3. For total billet costs, the difference tends to be almost twice as great. Yet E-1 positions never appear anywhere other than in total inventories of Naval manpower. The effect of this is that large start-up costs which should be included elsewhere are "buried" by the BCM in E-1 and/or year-one line items. PCS costs are a prime example. This problem is recognized and remedied to a very minor extent in the treatment of School Costs, although it remains a fundamental concern. It will be discussed in a broader context later.

A second concern is that two components, Government Furnished Quarters-Imputed (not be to confused with Basic Allowance for Quarters) and Commissary, are definitely "average" rather than marginal costs. As such, they should not be included. It is likely that the same is true of a large portion of the Medical/CHAMPUS estimate, although that determination cannot be made without the data on which the estimate is based.

I.4.5. Proficiency Pay

Estimation Procedure - Proficiency Pay is awarded to certain personnel in shortage specialties, recruiting and other special duty. At present, although it is identified as a separate cost element in the billet model, no provision is made for its estimation.

Anlaysis - The FY78 budget includes some $16.2 million for Proficiency Pay. Of this, $10.1 million is paid to approximately 7,350 nuclear-trained petty officers in four principal skill ratings: MM, IC, EM and ET. The remainder is distributed over a broad cross-section of other ratings. The fact that Pro Pay is omitted from the model constitutes a problem, albeit an understandable one, given the difficulty of identifying the cost with specific ratings or grades. With the increased access to Joint Uniform Military Personnel System (JUMPS) data, it may be possible for the first time to develop meaningful estimates for this element.

I.4.6 Constant Cost/Year

Estimation Procedure - Constant Cost/Year represents a collection of cost elements which are thought to vary with year of service rather than with occupational skill or grade. Estimates of the individual components are

developed outside the model, principally from budget data. They are then input as totals per year. The elements included in Constant Cost/Year, together with their appropriation categories and cost estimates for selected years are shown below:[4]

Element	Costs YR.16	YR.5	YR.2	YR.1	Appropriation
Accession Clothing	$ —	$ —	$ —	$ 332	MPN
Basic Clothing	—	—	60	—	MPN
Standard Clothing	86	86	—	—	MPN
E-7 Clothing Allow.	225	—	—	—	MPN
Int. on Savings	8	8	8	—	MPN
Death Gratuity	4	4	4	4	MPN
Disability Provision	20	20	20	20	DOD
Messing & Subsistence	967	967	967	967	MPN
Prisoner Apprehension	1	1	1	1	MPN
Command & Admin.	436	436	436	436	O&MN
Recruitment	—	—	—	506	O&MN
Dependent School	51	51	51	51	O&MN
Insurance	6	6	6	6	O&MN
	$1,804	$1,579	$1,553	$2,323	

Analysis - The two remarks made earlier with respect to Constant Cost/Grade also apply here. First, two rather large components, Command & Administration and Recruitment, and a smaller one, Dependent School, are certainly examples of costs which will not vary with a marginal billet change. They should be deleted.

[4]This breakout was also obtained from B.K. Dynamics, Inc. These costs are identical to those which appear in the FY78 BCM runs. The data assume that promotion to E-7 occurs in year 16. This is true only in selected cases.

As before, a secondary concern is with the large year-one costs which should preferably be treated in the nature of an investment. Also, the model's procedure of transferring LOS costs to grade costs on the basis of median service length produces some odd results with Constant Cost/Year. First, if median service length for an E-2 is less than one year, as it is in a number of cases, both E-1's and E-2's in that rating are charged with recruitment and accession clothing costs. And, since median service length for E-7's tends to be different (greater) than the year in which the E-7 clothing allowance is paid, that cost is often omitted altogether from the cost-by-grade matrix, or in a few cases is actually charged against other grades. Corrections for these anomalies could be easily coded into the model, but that would not alter the fundamental problem of using MSL data to generate costs by grade.

I.4.7. School Cost

Estimation Procedure - Before discussing the model's estimation of school costs (which is quite involved), it is important to note that contrary to what is stated in the BCM User's Manual, these costs presently include all of the following elements reported by individual Naval Training Centers:

- Command & Staff Overhead
- Departmental Overhead
- Division Overhead
- Direct Course Costs
    - Military labor (instructor and other)
    - Civilian labor (instructor and other)
    - Supplies
    - Contractual & miscellaneous services
    - Training equipment maintenance
    - Equipment depreciation
    - Student salaries

Rather than write an explicit analytic expression for the way School Costs are treated in the model, it is more instructive to describe the general nature and intent of those computations. (It turns out that the algorithm in the model contains an apparent arithmetic or programming error which systematically understates costs. The nature of the error and its proposed correction are outlined in Appendix A.) First, aggregate training costs for each rating by LOS are developed outside the model, principally by matching student records from the Navy Information Training System with course costs reported by the Resource Management System. These are input together with a corresponding set of "inventory" data, i.e., number of personnel, by rating. The ratio of these two inputs provides a measure of training costs per man, per year. However, that ratio is never actually computed by the model. Instead, each year's aggregate training costs are "spread" into successive years on the basis of: (1) a set of statistics on "average number of men per year" which are computed within the model; and (2) separation probabilities, calculated from a rating-specific input vector of "continuance rates." In general, the greater the likelihood of separation, the higher the percentage of training costs assigned to early years, and vice versa. The inventory data are eventually summed and used in an attempt to ensure that the final cost estimates by LOS are not distorted by the artificial "average number of men per year" calculated by the model.

Analysis - To begin with, there is a strong reason to question the adequacy and reliability of the basic input data. Those data are, first of all, the product of a cost accounting system in which roughly a third of total cost consists of some type of overhead charge. Those numbers are not likely

to provide a good basis for estimating the cost consequences of marginal billet changes. Of even greater concern, however, is the extremely complex, time-consuming and costly data processing requirements needed to generate the model's input. Because of the extreme comprehensiveness of those requirements, the school input may lag the model's other data by two fiscal years, and the inputs are, as a practical matter, nearly impossible to disaggregate and verify. An effort to do that for one rating/LOS was made during the study. Although not entirely conclusive, the results suggest the possibility of substantial divergence between the BCM's school cost inputs and the actual magnitudes they are intended to represent. Details are furnished in Appendix B.

Except for the technical error mentioned above, there is nothing in principle "wrong" with the model's present algorithm for allocating school costs forward. In practice, however, it can produce some curious and perhaps misleading results. As an example, consider the FY78 model's school cost estimates for the ASM rating, LOS 16-20:

LOS	School Cost
16	$19,861
17	9,503
18	11,244
19	9,634
20	9,213

These numbers clearly have no real-world meaning. Inventory data show no one in the rating past LOS 19, and the highest grade to be E-5. It may well be that the complicated system for generating inputs, together with the allocation algorithm which is based on often erratic continuance rates, simply does not produce reliable results. An alternative approach, which is radically simpler than the present system, is described in Appendix C.

I.4.8. Transport Cost

Despite the fact that the model provides a separate cost element for Transport Cost - meaning PCS - these costs are now included in Constant Cost/Grade. This is a relatively large cost item, but so also are several other components of Constant Cost/Grade and Constant Cost/Year. Leaving these in the constant cost elements creates no particular problem, provided they are updated when required and are individually visible in some fashion to potential users of the model.

I.4.9. Reenlistment and Settlement Costs

Estimation Procedure - This element includes only reenlistment costs. There was a time when cash "settlement" payments were made for early termination of service, but such payments are no longer made.

Rating-specific vectors of reenlistment costs by LOS are developed outside the model and "thruput," i.e., printed in the output in exactly the same form. For all ratings the costs begin in LOS 5 and terminate after year 20. For approximately one-fourth of the ratings (the highly technical ones such as aviation ASW, boiler, communication, electronic, machinist, missile, radio and sonar technicians), the cost is level for the first four years (LOS 5 through 8), and then rises to a new level for the remainder of the period. For all others it is level throughout. More than 40% of the 93 ratings show constant annual costs of $125. In only one case (missile technician) is the cost reported to be more than $1500 per year.

Analysis - The Navy's reenlistment bonus program is in a period of transition. Recent legislation establishing the Selective Reenlistment Bonus (SRB) entitlement has eliminated the former Regular Reenlistment Bonus (RRB) and Variable Reenlistment Bonus (VRB) programs. However, RRB and VRB payments are currently being made under prior obligations. The following data apply to the FY78 Budget[5]:

Program	No. Receiving	Avg. Payment	Total Entitlement
RRB	9,549	$1,111	$10,609,000
VRB	6,577	1,137	7,479,000
SRB:			
New Payments	10,747	1,984	21,322,000
Anniversary Paymts.	29,152	1,641	47,852,000
	56,025		$87,262,000

For purposes of the Billet Cost Model, whose objective is to estimate future costs on the basis of current information and experience, it would seem that RRB and VRB costs should be ignored. They will shortly phase out, and at present represent only some 20% of total reenlistment costs. This would drive to zero the reenlistment cost estimates for a majority of ratings in the model since BUPERS Notice 1133 series indicates that something on the order of two-thirds of all ratings are not SRB-eligible.[6] BUPERS Manual 1060040 states that SRB payments cannot be made beyond the twelfth year of service. While on the surface this might suggest that for eligible ratings the annual cost stream should terminate in year 12, it is probably best that these costs be at least partially capitalized.

[5]Source: Dept. of the Navy, Supporting Data for Fiscal Year 1979 Budget Estimates Submitted to Congress, January 1978.

[6]It should be noted that eligibility is not constant but instead subject to semiannual review.

I.4.10 Retirement Cost

Estimation Procedure - There has been an evolution of methods for estimating retirement costs in the BCM. The earliest involved use of a constant percentage of base pay for all ratings, grades and LOS[7]. Later, estimates were conditioned on retirement probabilities. For example, the likelihood of retirement - given LOS 16 had been reached - being greater than for LOS 4, a higher percentage of base pay was charged against year 16 than year 4. The model's present and preferred method is described in a BUPERS unpublished paper entitled, "Retirement Costs of the Active Enlisted Force." That method begins by computing the present value of the annuity due a person retiring at each possible grade in each possible LOS. The next computation is to determine an equal annual amount - called a sinking fund payment - required in each year prior to retirement to accumulate to the amount of the annuity. (The annual payments are compounded at a given rate.) Finally, for each rating and LOS, the probability of retiring at each possible year/grade combination is multiplied by the combinations's associated sinking fund payment, and the sum of those products (an expected value) is treated as the annual retirement cost.

Analysis - This is a complex area of analysis. It is complex, first, because it involves sophisticated actuarial mathematics. Second, it deals with the moderately distant future about which there is considerable uncertainty. Finally - and perhaps worst of all - it does not lend itself to a unique solution. There is a near infinity of assumptions and procedures

[7]Nothing more recent than this has been described in any official documentation of the model.

which are admissable by practically any standards. Appendix D presents a comprehensive discussion of the issues and alternatives involved in estimating retirement costs. The interested reader is encouraged to review that in its entirety. The following is a brief summary of this study's position on the matter.

Up to the point of vesting, i.e., the earliest time in service at which a member becomes eligible for an annuity, the treatment of annual costs is largely arbitrary, subject to the constraint that the amount of the annuity due at vesting has been provided for, i.e., accrued. Some procedure which reflects the likelihood of continuation to vesting is preferred. After vesting, however, a single method can be recommended as correct for purposes of manpower cost analysis. The retirement cost in each year after vesting is the amount by which the present value of the annuity changes in that year. An important implication of this is that, for late years, the cost may be quite low or even negative as the effect of reduced life expectancy overtakes other factors in the benefit formula.

Regardless of whether the model's present sinking fund method or the "obligations accrual" approach described above is used, it is extremely important that the median-service-length statistic not be used to generate grade costs. For example, the AT E-9 retirement cost shown in the most recent BCM run is $1,941. That is an LOS 22 value corresponding to a MSL of 21.2. The weighted average cost based on the actual LOS distribution of E-9's is $1,854. For the obligations accrual method, differences would be much greater because of the more rapid decline in yearly costs after they have reached their peak.

I.4.11 Total Cost

Total Cost is definitionally equal to the sum of the preceding elements. It requires no discussion.

I.4.12 Down Cost

Estimation Procedure - Down Cost is defined in the BCM as the cost associated with "non-operational billets," i.e., students, transients, patients or prisoners. It is computed as:

$(1 - A_i)$(Total Cost - School Cost)

where, A_i is a rating-specific measure of the fraction of operational time available in year "i". The expression $(1 - A_i)$ is down time in decimal form. Computed from MTA, TPP and other related input vectors, it is largest in year 1 where the model assumes all of E-1 time as "down" plus a fraction of E-2 time. The measures tend to be nearly the same for all ratings, with year 1 down time being approximately .55.[8] It is typically less than .10 for succeeding years. The rationale for subtracting School Cost from Total Cost is to avoid double counting. Down Cost is a kind of pipeline concept; the idea being that direct costs of training have already been picked up in Total Cost, and this element is reflecting the other manpower-related costs necessary to "back-up" the operational time available from a billet.

Analysis - There are two "problems" with the model's treatment of Down Cost, the first being more a matter of inconsistency between documentation

[8]The procedure for computing down time for LOS 1 has apparently changed significantly between the FY77 version of the model (which the above data refer to) and the FY78 version. Values now for LOS 1 are on the order of .05 to .07.

and practice than a substantive technical problem. It is apparent from inspection of the Op-102 Enlisted TPS&D Report that student time is not included in the billet's estimate of Down Cost. For example, the TPS&D Report for the FY77 shows the ratio of student to total billets for E-4's in the ETN rating to be .289. The ratio for the remainder of down billets (transients, patients, etc.) is .097. The combined down time in decimal form is thus .386. The BCM's corresponding value is .082. It turns out, however, that since student pay and allowances are included in the model's estimate of school costs, it is appropriate that they not be included in Down Cost.

The second problem concerns the formula used in computing Down Cost. To put the matter in perspective, consider the simple case where there are no school costs and the availability ratio is .5. In other words, there is one "down" billet for each "up" billet. Clearly, then, billet cost should be twice total cost. Algebraically this is:

$$B_i = \frac{T_i}{A_i} = \frac{T_i}{.5} = 2T_i \quad ,$$

where, "i" denotes LOS. Down Cost being the difference between billet cost and total cost, it is computed as:

$$D_i = B_i - T_i = \frac{T_i}{A_i} - T_i = T_i\left(\frac{1-A_i}{A_i}\right) = T_i\left(\frac{1-.5}{.5}\right) = T_i$$

Now, provided that available time is defined to include student time; i.e., down time consists only of transients, patients, and prisoners, no change is required in the above relationships. Total Cost simply includes school

cost as one of its elements, and it is multiplied by $(1-A_i)/A_i$ to estimate Down Cost.

I.4.13. Billet Cost

Billet Cost is definitionally equal to the sum of Total Cost and Down Cost. It requires no discussion.

I.4.14. Proposed Additions to the BCM Cost Elements

Given the model's objective of including all manpower-related costs to the U.S. Government - explicit and implicit - there are two logical candidates for addition to the present set of elements. The first might be labeled "Non-DOD Cost." It would include payments made annually by the Veterans Administration for educational benefits, and for compensation to survivors of deceased active duty or retired military personnel. Those two costs are not now reflected in the model. (A third Non-DOD cost, unemployment benefits paid to former service members by the Labor Department, is presently included under Constant Cost/Grade. For the sake of organizational consistency, that cost should probably be transferred to the new element described here.) Based on information compiled recently by the Office of the Assistant Secretary of Defense (Comptroller), future VA educational benefits currently being accrued are of a negligible amount.[9] That is not the case, however, with dependency and indemnity compensation (DIC). The OASD estimates of those costs on an annual basis, by grade, are[10]:

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[9]OASD (Comptroller), Average Cost of Military and Civilian Manpower in the Department of Defense, December 1977. p. 16.

[10]ibid.

Grade	Cost
E-1	$ 60
E-2	60
E-3	60
E-4	50
E-5	96
E-6	178
E-7	304
E-8	382
E-9	435

Until more current or otherwise better data become available, it is recommended that the above estimates be incorporated in the billet model.

The second cost element proposed for addition to the model might be called, "Tax Adjustment Cost." This element represents the implicit cost to the U.S. Treasury stemming from the fact that military quarters and subsistence allowances are not subject to personal income tax. Inasmuch as this is an implicit cost, its relevance is frequently both overlooked and debated. However, it comes into very sharp focus when comparisons are made between military and civilian manpower costs. For such comparisons - and indeed, for any cost analysis - to be meaningful, all costs must be expressed on a consistent basis. In this case consistency refers to the measurement of gross (meaning before-tax) costs to the U.S. Government. Assume for a moment there were a single tax rate - say 20% - applicable to all personal income, and that all taxes are fully withheld. The Government would be absolutely indifferent between: (1) a taxable quarters and subsistence allowance of $1,000 per year; and (2) a non-taxable allowance of $800. The service member would be equally

indifferent. The absence of such a uniform tax structure only complicates the estimation problem; it in no way refutes the logic of the argument. The foregone tax is a relevant cost.

The OASD has developed the following estimates of annual tax adjustment costs by grade, based on FY77 pay scales[11]:

Grade	Cost
E-1	$ 410
E-2	441
E-3	486
E-4	580
E-5	671
E-6	694
E-7	732
E-8	794
E-9	1,026

Until more precise estimates become available, the above - properly escalated - are recommended for use in the billet model.

[11] ibid.

I.5. SELECTED TOPICS

There are a number of additional aspects of the Billet Cost Model which bear on its adequacy and usefulness, and which transcend the model's individual cost elements. They are:

- Continuance rates
- Development of costs by grade
- Generalized billet costs
- Manpower supply shortages
- Officer costs
- Model documentation

In this section each of those will be discussed in turn.

I.5.1 Continuance Rates

There is a tendency on the part of some who are familiar with the BCM to think of continuance rates as being of central importance to the model. However, they are used only in the estimation of retirement and training costs, and in the latter only because they are part of the particular method used for allocating those costs. In any event, the Billet Cost Model - by design - accepts as input any set of continuance rates for a rating. These rates are

probabilities that an individual in service who has attained longevity i, will attain longevity i+1. They are measures of the probability that service will continue for at least one more year.

Continuance rates are computed externally from personnel inventories made by the Navy (so-called FAST actuals), which are also the source of the model's other inventory inputs. The difficulties of using data drawn from such a source have left traces inside the model itself. Certain coded hedges are provided against the possibility of continuation rates exceeding one, or exactly zero. The existence of these hedges is certainly not "bad." In fact, safeguards of this type are often standard features of large computer programs. In this case, though, they seem to be uniquely related to continuance rates, and to anticipate the input of implausible values. Further description of the computation of continuance rates for the BCM appears in Appendix F.

Apart from the normal difficulties encountered because of errors in inventory data, the central difficulty of continuance rates estimation is that it must confront - as the model does not- the fact that personnel are transferred from one rating to another. A 1977 inventory shows 459,707 personnel in all. A 1977 lateral transfer count shows 74,609 transfers. About one man in six is transferred in each year. It appears to be true that present estimation of continuance rates does not make use of data on transfers, and would not benefit much if it did. The available inventory data are erratic for such small ratings as Engineering Aids and not entirely satisfactory for populous ones like Boatswain's Mate.

Despite what appears in the model's documentation, it is clear that any attempt to make estimates for a series of years and smooth (by a weighted-average) the results has been abandoned. Present input rates are based on a single pair of integers and are calculated by methods oriented to rounding out inventory error and transfer effects in simple ways, without regard to any "niceties" of estimation. All of this, of course, raises the question of whether the amount of fine structure formally used and generated by the BCM -- from input, through calculation, to output -- in the estimation of training and retirement costs may in fact produce results which, in the case of small ratings, are little more than slightly edited "noise," and are *not wholly satisfactory* for more populous ratings.

A variety of approaches might be pursued to deal with this situation, the most obvious being the attempt to form rating groups between which transfers are rare, large enough to be reasonably free of transfer effects. Equally obvious is to examine the inventory process -- at least inventory records -- to assess the sources of anomalous counts. A little less direct is to routinize the assembly of monthly data for such purposes as replacing "spot" data by annual averages. This approach leads into use of the data over several years as material for simultaneous estimation of vectors of continuance rates presumed to be stable, or allowed to have simple trends, once transfer counts have been applied. Thus three years' worth of data provides two observations of any one continuation, as from year 6 to year 7. This permits estimation of a continuation rate, and a degree of freedom for "error" or, possibly, estimation of a trend.

What is done now appears to be only a coarse starting point; and it is entirely possible that the source data can support little that is appreciably better. But if not, then some marked simplifications in the model appear to be in order.

I.5.2. Development of Costs by Grade

Inasmuch as billet requirements within the Navy are identified and managed by rating and grade, the BCM's products of primary importance are cost estimates by rating and grade. The model presently develops its grade costs by transferring, on the basis of median service length in grade, a single year's estimate from the LOS matrix. In the element-by-element analysis, the point was repeatedly made that this is an unsound procedure. In cases where the actual LOS distribution within grade is asymmetric, and in cases (such as training and retirement) where there is significant year-to-year variation in cost, this procedure can produce quite unrepresentative estimates for a given grade.

Resolution of the problem cannot be achieved by the simple adoption of an alternative procedure. Instead, it lies in adoption of what is in some respects a fundamentally different approach to the development of billet costs. That approach would recognize, first, the definition of billet cost as the sum of several individual cost elements. Grade-specific estimates for each of the elements would be developed in different ways, most of which would not require the intermediate computation of cost by LOS. In other words, estimates of individual elements would become a set of billet cost "building blocks" which - with one exception to be discussed in the next paragraph - would ultimately require nothing but simple addition. To be sure,

generation of the estimates for each element would have its own input and computational requirements. As mentioned in Section I.4, manpower inventory data (and the tapes on which those data are contained) would occupy a central role in many of these computations. In fact, because of the diversity of input and processing requirements, it is perhaps best both conceptually and practically to think of development of the various estimates as several independent processes which would ultimately be summarized in a single set of output. (In the Recommendations section of this document, that output will be described in terms of an annual Billet Cost Report.)

The exception mentioned above stems from the need to capitalize manpower "start-up" costs. In part because structured billets are not written below the E-3 level, and in part because of the considerable amount of formal and informal (on-the-job) training which takes place at the E-1 and E-2 level, the suggestion here is that the entirety of year-one (meaning E-1 and E-2) costs be capitalized.

As mentioned earlier in the discussion of school costs, there is no uniquely correct or even clearly preferable method by which to effect this forward allocation of costs. Purely for the purpose of illustrating the quantitative results of one such allocation, the following example is presented.

Algebraically, the method may be described as:

$$T^*_j = T_j + K$$

$$K = \frac{\sum_{j=1}^{2} N_j (T_j - S_j)}{\sum_{j=3}^{9} N_j}$$

$$B^*_j = \frac{T^*_j}{A_j}$$

where,

T^* = *total cost with capitalized start-up*

T_j = nominal total cost (BCM col. 12)

K = capitalized start-up cost

N = annual strength

B* = billet cost with capitalized start-up

A = annual operational availability (defined to include student time)

j = grade

The idea is that total annual cost for E-1's and E-2's, represented by the numerator of K, is distributed uniformly over the remaining billets in the rating. (School cost is removed from the total to avoid the BCM's double counting of students.) The fully capitalized total cost is divided by annual operational availability (reference Section I.4.12) to generate the capitalized billet cost. Sample data and results (applicable to the RM rating) are shown below.

Grade	Annual Strength*	Total Cost**	Total less School Cost**	Capitalized Start-up Cost	Annual Availability*	Capitalized Billet Cost
E-1	204	$11,145	$9,953	—	—	—
E-2	1,446	11,333	9,099	—	—	—
E-3	2,709	11,747	—	$ 998	.944	$13,501
E-4	3,707	12,789	—	998	.943	14,620
E-5	4,092	14,932	—	998	.954	16,698
E-6	2,730	19,103	—	998	.958	20,982
E-7	1,450	22,201	—	998	.961	24,140
E-8	369	23,967	—	998	.965	25,870
E-9	149	25,381	—	998	.966	27,307

*Source: Op-102 Enlisted TPS&D Report, 30 September 1977

**Source: FY78 Billet Cost Model

Note that mainly because of the small share of total billet strength represented by E-1's and E-2's, the effect of the allocation is to increase nominal total cost by only 4-9%. While not representative of all ratings, these results are certainly not atypical.

I.5.3 Generalized Billet Costs

It is widely recognized that in early stages of the weapon system development process, needs arise to conduct manpower-hardware trade-off analyses when it is not possible to define manpower requirements by rating and grade. In fact, some participants and observers of that process have argued that the potential for realizing the greatest economies through trade-offs is at precisely those times. The rationale is that when manpower requirements can be defined at the level of the Billet Cost Model (by rating and grade), hardware designs are relatively fixed and substitutability prospects are limited. Whatever the merits of that argument, it seems reasonable for this study to inquire into the feasibility of developing manpower cost measures at a level of generality higher than rating and grade, but which still retain some sensitivity to occupational categories and training/experience level.

The following groups of ratings appear to be both logical and useful, and have the added advantage of being officially recognized in Occupational Standards Manual (NAVPERS-18068D):

1. General Seamanship (BM, SM)
2. Ship Operations (OS, QM)
3. Marine Engineering (BT, EM, EN, GS, IC, MM)
4. Ship Maintenance (HT, IM, MR, ML, OM, PM)
5. Aviation Maintenance/Weapons (PR, AX, AE, AT, AQ, AD, AZ, AO, AM)

6. Aviation Ground Support (AB, AS)
7. Air Traffic Control (AC)
8. Weapons Control (ET, FT)
9. Ordnance Systems (GM, MN, MT, TM)
10. Sensor Operations (EW, OT, ST)
11. Weapons Systems Support (TD)
12. Data Systems (DP, DS)
13. Construction (BU, CE, CM, EA, EO, SW, UT)
14. Health Care (DT, HM)
15. Administration (LN, NC, PN, PC, YN)
16. Logistics (AK, DK, MS, SH, SK)
17. Media (DM, JO, LI, PH)
18. Musician (MU)
19. Master-at-Arms (MA)
20. Cryptology (CT)
21. Communications (RM)
22. Intelligence (IS)
23. Meteorology (AG)
24. Aviation Sensor Operations (AW)

As for generalization across grades, interviews with Op-01 and BUPERS staff have resulted in the following:

Classification	Grades
Apprentice	E-1 through E-4
Journeyman	E-5 through E-6
Supervisor/Manager	E-7 through E-9

From a computational point of view, a natural approach would be to develop weighted averages from individual billet costs and inventory data. The generalized cost would be computed as:

$$G_{mn} = \frac{\sum_j \sum_k B_{jk} N_{jk}}{\sum \sum N_{jk}}$$

where,

G = generalized billet cost

B = billet cost

N = annual strength (inventory)

m = training/experience level

n = occupational class

j = grade

k = rating

As an illustration of the procedures and results, consider "Ship Operations Manpower," defined to include the OS and QM ratings. Data are shown below.

Grade	OS Billet Cost*	OS Inventory**	QM Billet Cost*	QM Inventory**
E-1	$12,029	78	$12,121	71
E-2	12,352	946	12,034	314
E-3	12,766	1,630	11,591	703
E-4	14,106	1,740	13,231	912
E-5	15,383	1,149	15,319	706
E-6	20,932	1,012	18,928	584
E-7	27,361	697	23,356	713
E-8	31,100	131	25,849	87
E-9	29,295	46	26,982	45

* Source: FY78 Billet Cost Model run

** Source: Op-102 Enlisted TPS&D Report, 30 September 1977

An example calculation for the Journeyman level is:

$$G = \frac{15{,}383(1149) + 15{,}319(706) + 20{,}932(1012) + 18{,}928(584)}{1{,}149 + 706 + 1{,}012 + 584}$$

$$= \$17{,}597$$

Complete results are:

Apprentice:	$12,954
Journeyman:	17,597
Supervisor/Manager:	25,950

I.5.4. Manpower Supply Shortages

It is clearly implicit in the BCM (or in any similar model) that a given billet requirement can be filled at the cost reported by the model. However, where persistent shortages exist in certain ratings - Boiler Technicians and Data Systems Technicians being notable examples - the actual cost of filling an incremental billet may be something quite different.[1] It is useful to examine the nature of that cost.

The concept of "opportunity cost" is directly relevant here. In economic theory, that is the cost concept of central importance. The cost of using an economic resource in a particular way (or not using it at all) is the opportunity (product) foregone by not using the resource in what would otherwise be its most productive capacity. That there might be a divergence between monetary cost and opportunity cost does not constitute a major problem in theory because of the proposition that, under competitive conditions, economic resources (factors of production) receive payments equal to their marginal product.

[1]The authors wish to acknowledge that this was first pointed out by Paul F. Hogan, Project Officer for the Manpower/Hardware Life Cycle Cost Analysis [illegible]

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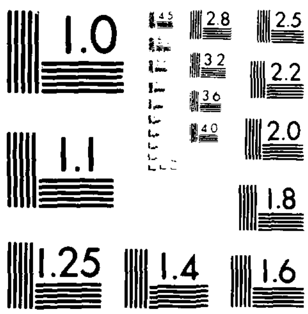
1.0
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1.8
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2.5
2.8
3.2
3.6
4.0

In the case of the Navy, given that a supply of, for example, BT's exists - albeit insufficient to satisfy total requirements - the true cost of filling an incremental billet from that supply is an opportunity cost; i.e., the consequences of foregoing the use of those services elsewhere.[2] Inasmuch as there is no practical way of quantifying such a cost, and on the premise that if quantified, it would be substantially higher than what the model presently reports, the only way the problem can be handled in the context of the BCM is to exclude the shortage ratings from the model's output of marginal costs. This would provide a signal to users of billet costs that additional requirements for the resources in question will be - at least in a qualitative sense - quite costly.

I.5.5. Officer Costs

The study's detailed discussion of officer costs appears in Appendix G. The following is a summary of that material.

There are two fundamental problems which have inhibited estimation of officer costs since the beginning of the BCM. They are: (1) defining a meaningful and useful set of officer "billets"; and (2) categorizing, quantifying and allocating training costs. As to the former, the following

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[2]This line of reasoning quickly leads to the conclusion that the true cost of the use of any Naval manpower is the opportunity foregone by not employing that manpower in the private sector. To some extent that conclusion is valid, although it is mitigated - certainly at the margin - by the existence of substantial unemployment in the private sector. Far more important, however, is the fact that, of necessity, the Navy is cast in the economic role of suboptimizer. Its objective, and that of the entire Defense establishment, is not to achieve optimal allocation of resources between the public and private sectors, but rather to manage what are essentially fixed monetary budgets, manpower ceilings, and numerous other constraints in such a way as to maximize the performance of its various missions.

"designators" have been used:

Surface line officer

Surface line officer - Nuclear trained

Submarine officer without sub pay

Submarine officer with sub pay

Submarine officer - Nuclear trained

Aviation officer (Pilot)

EDO, LDO, Supply

EDO, LDO, Supply - Submarine trained

Except for the need for further aviation officer detail, these are probably adequate for the types of trade-off decisions that would use BCM estimates.

Proper treatment of officer training costs is not a trivial problem. The major categories of those costs are:

- Pre-accession training
- Post-accession training
  - General
  - Special

Pre-accession training is in the nature of a start-up cost and should be capitalized over all designator grades, similar to the treatment of E-1/E-2 costs for enlisted manpower. Post-accession training costs of a general nature (e.g., Command and Staff College, Naval War College/National Defense University) would not be expected to vary with marginal officer billet changes and should therefore be excluded from the model's cost base. Specialized post-accession training (e.g., lead-in flight familiarization and advanced flight training) do constitute relevant costs and should be estimated and allocated, at least conceptually) the same as enlisted training.

I.5.6. Documentation

The Billet Cost Model's documentation, cited at the beginning of Section I.3, is both outdated and incomplete. Since publication of the most recent portion of the documentation, the 1976 User's Manual, the model's treatment of three important elements - School, Retirement and Down Costs - has changed significantly. Moreover, the manual's description of the model is extremely incomplete. In fact, so much so that it is not clear for whom it is intended. A weapon system designer or cost analyst who wishes to understand the assumptions, source data and computational procedures which underlie the estimates will find the documentation to be of little assistance. Nowhere in the narrative is there an example calculation. The following, taken from p. 28 of the 1976 manual, is representative of its description of how the estimates are generated:

$$A_i = \frac{\text{Annual item cost}_i}{N}$$

where,

A = annual cost

N = on-board force or average man-years as appropriate

i = year

Sample input data are provided for one rating, as are sample outputs, but they are for different ratings. It is therefore not possible to determine what operations are performed on the inputs. In short, from the point of view of a user of manpower cost estimates, the BCM is essentially undocumented.

If the ultimate result of this study were to be simply a modified Billet Cost Model, then a good deal of the description appearing in Sections I.3. and I.4. of this report might be incorporated in a new set of documentation. Much else, of course, would be needed. In particular, since the sum of Constant Cost/Year and Constant Cost/Grade can be as much as 40% of total billet cost, it is very important that the components of each of those be clearly defined in terms of the program elements and appropriations to which the underlying data relate. Also, estimates of each component within those two elements are of considerable interest and importance, especially since a given application might require that they be modified.

As will be explained in the final section of the report, it is recommended that the ultimate result of this study be a new report rather than a modified Billet Cost Model. Naturally, either modified or new computer programs would be needed to generate much of the report's contents, but emphasis would shift from documenting a model to documenting a set of annual manpower cost estimates. Requirements which that documentation should meet are discussed in Section III.

I.6. REMEDIAL ACTIONS RECOMMENDED

To a considerable extent, this section will simply be a summary of the discussion and analysis that has preceded it. Its main purpose is to collect in one place all changes recommended with respect to the BCM's present cost-estimating procedures. (Here "procedures" is defined to include data sources as well as computational methods.) The scope of this section is somewhat limited in that it is concerned only with remedial actions necessary for the billet model to do better what it presently attempts to do. Left for Section III is the matter of how the Navy's manpower costing needs can best be served.

The discussion is in two parts, the first corresponding to Section I.4. and the second to I.5.

I.6.1. Element-by-Element Changes

Base Pay - No requirement exists to estimate base pay by LOS. Weighted-average base pay by grade should be computed by processing the most recent inventory data tapes (LOS disbribution within grade, by rating) against the current statutory base pay table.

Hazard Pay - No requirement exists to estimate hazard .(incentive) pay by grade. Hazard pay should be developed by first computing, from the most recent inventory data tapes and current statutory hazard pay table, full weighted-average hazard pay by grade. For each rating eligible for this pay (approximately 40% of the total), there should be two cost estimates. The first is the full cost described above, and the second is zero. (There would

be a total billet cost corresponding to each). For all other ratings the estimate would be zero.

FICA - No changes are required in the computation of FICA costs. However, the documentation that accompanies the estimates should point out that in uses of the estimates where all FICA costs are visible (e.g. billet vs. billet trade-offs), they are not a relevant manpower cost and should be excluded.

Constant Cost/Grade - Two components of this element, Govt. Furnished Quarters-Imputed and Commissary, are average rather than marginal costs and should therefore be deleted. Further information is needed on the Medical/CHAMPUS estimate before a determination can be made.

Proficiency Pay - An effort should be made to obtain analytical/derivative reports from the JUMPS system to establish a data base from which to estimate proficiency pay costs by rating and grade.

Constant Cost per Year - Three components of this element, Command & Administration, Recruitment and Dependent School, are average rather than marginal costs and should therefore be deleted.

School Cost - It is not entirely clear what constitutes the preferred remedial action for school costs. However, two things about the present procedure are clear. First, the input data embody a large amount of costs that will not vary with marginal billet changes. In fact, a case can be made that student costs are the only truly variable component. Second, those inputs in combination with the model's allocation scheme generate results which can at best be characterized as "suspect." If it were possible to

incorporate an audit, verification and quality control system into the present procedures - which seems doubtful - they could be retained. Otherwise, adoption of a radically different and simpler approach such as described in Appendix C is recommended.

Transport Cost - With PCS costs included in Constant Cost/Grade, transport cost should be eliminated as a separate cost element.

Reenlistment and Settlement Cost - An effort should be made to obtain analytical/derivative reports from the JUMPS system to establish a data base from which to estimate reenlistment and settlement costs by rating and grade. The estimates should be annualized over the applicable periods of reenlistment, and should relate only to the Selective Reenlistment Bonus (SRB) entitlement.

Retirement Cost - The "Obligations Level Interpolation" method described in Appendix D should replace the BCM's present retirement cost method. The two produce very similar results for LOS 1-20, but the former reflects the true marginal cost of retirement after LOS 20. Costs by grade should be estimated by weighted-averages computed from inventory data and the LOS retirement costs.

Additional Elements - Two additional elements, Non-DOD Cost and Tax Adjustment Cost, should be added to the BCM's present set of elements. Estimates of these elements, in FY77 dollars, are available by grade in the OASD (Comptroller) manpower cost report of December 1977.

Total Cost - Total cost should remain the sum of all preceding elements.

Down Cost - Down cost should be estimated by T(1-A)/A, with the "down time" defined (and measured) to exclude students whose costs have been included in school cost.

Billet Cost - Billet cost should remain the sum of total cost and down cost.

I.6.2. Other Changes

Continuance Rates - An effort should be made to improve the quality of continuance rate input data either through refining the basic inventory data from which they are estimated, or by developing sufficiently large and homogeneous sets of ratings to be free of transfer effects. The sets described in Section I.5.3. should be used as a starting point.

Costs by Grade - The general approach of first developing costs by LOS and grade costs from those should be replaced by an approach which recognizes that requirements for grade cost estimation vary between cost elements. Total costs of E-1's and E-2's should be recognized to be of an investment or start-up nature and capitalized over the remaining grades in the rating.

Generalized Billet Costs - Billet costs should be developed for the twenty-four occupational classes and three skill/experience levels defined in Section I.5.3. by methods described in the same section.

Manpower Supply Shortages - Ratings for which total requirements persistently and critically exceed available supply should be excluded from the model as a signal to potential users that the opportunity costs of additional requirements in those ratings are very high.

Documentation - If this study results only in a modified Billet Cost Model, a completely new set of documentation should be prepared, using much of the descriptive material contained in this report. More important documentation, however, would be that which accompanies the annual Billet Cost Report described in Part III.

PART II:

ALTERNATIVE SOURCES OF NAVAL MANPOWER COSTS

II.1. MODELS AND OTHER SOURCES

This study's second major objective was to perform - quoting from the original Request For Proposal - "an evaluation of other existing Navy manpower cost models." Motivation for this is the fact that frequently manpower requirements are not defined in sufficient detail to permit full use of the BCM. In carrying out this objective, a decision was made to interpret liberally the meaning of "other existing Navy manpower cost models." In effect, this was taken to mean "alternative sources of Navy manpower costs." It is of little importance whether such alternative measures are generated by a formalized model. Provided they are readily available, well documented and of general applicability, they should be given consideration in the present context. Three such sources were identifed. Because they are well documented and also widely recognized throughout the Navy, the description provided here will be relatively brief. Section II.2. will present the results of using each of the sources, as well as the BCM, to develop manpower costs for a selected aircraft squadron, surface ship and nuclear submarine.

II.1.1. Navy Resource Model (NARM)

The Navy Resource Model is a data management system, the objective of which is to estimate the costs of alternative Naval force structures. The Navy Program Factors Manual, often thought of as synonymous with the NARM, is in fact one of its derivative products. That manual was designed for use in estimating dollar and manpower resources required for the operation and support

of ships (by class) and aircraft (by type/model/series) within individual program elements. The estimates are updated and published annually in a revised factors manual, the most recent of which is dated 31 August 1977 and distributed by OPNAV-901M.

Manpower costing in the NARM is accomplished in two phases. Direct MPN costs (for a specific ship class or aircraft T/M/S) are estimated as follows:

$$A_i \times Z \times W_i$$

where,

A = manpower allowance

Z = NARM Direct MPN factor

W = weighting factor

i = aircraft T/M/S or ship class

The manpower allowance is generally consistent with the applicable manpower authorization document. The MPN factor is developed by a sub-model known as QUIKPAY.[1] Until recently, the NARM used a single MPN factor for all officers and another for all enlisted. There is now a direct and an indirect factor for each. The weighting factor, supplied by BUPERS, varies around 1.0 and can be thought of as adding a qualitative dimension to the gross manpower requirement represented by A.

Second-phase estimation centers on manpower-related indirect support costs. Again, these estimates are tied to an individual aircraft or ship, but consist of elements identified in the BCM and elsewhere as uniquely associated

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[1]That model is documented in a Center for Naval Analyses report, Users Guide to the QUIKPAY Model, CRC 272, September 1975.

with manpower: recruiting and examining, training, PCS, base operating support, medical support, transients, patients and prisoners. (There is also a set of logistics support elements. However, they are not considered relevant for purposes of manpower cost analysis.) Generally speaking, estimates of these elements are generated by applying a set of "multipliers" to the direct officer and enlisted manpower requirements. A complete description of the methodology appears in Appendix E.

As a source for producing manpower cost estimates, the NARM has one feature which is both an advantage and a disadvantage. It requires a minimum amount of information with respect to manpower requirements/characteristics. That is a decided advantage in some cases. However, when detailed information is available, that information is of little use except for possibly refining W_1, the weighting factor.

The ready availability of the NARM's indirect support methodology is another advantage, provided it is viewed in the proper context. Implementation of that methodology results in the estimation of average rather than marginal costs. A large share, and in some cases all, of the costs of manpower-related support activities are allocated to only those billets directly associated with ships and aircraft. For the uses to which the NARM and its derivative products are typically put, this is as it should be.

An additional feature of the NARM is that it is a short-to-intermediate-run model. This means, as indicated above, it treats a portion of support costs as fixed. Thus, despite the fact that its estimates will include elements not contained in the BCM such as hospital staff and base operating

support personnel, the BCM's numbers may be higher because of the "fixed costs" excluded from the NARM. One of the purposes of the empirical cost comparisons in Section II.2. is to bring this matter into sharper focus.

II.1.2. Navy Composite Standard Rates (CSR)

Composite Standard Rates for costing all military manpower are prescribed in Section 252, DOD Accounting Guidance Handbook (DOD 722-0.9-H). The rates are essentially averages for all personnel in a grade. They include basic, incentive and special pay as well as other allowances (e.g., quarters, subsistence, separation, uniform) and expenses (e.g., FICA, bonuses, life insurance). Except for PCS, this covers the totality of costs included by the Military Personnel appropriation. Navy-specific rates are accompanied by a procedure for costing PCS moves, depending on whether they are foreign or CONUS. In addition, an "overhead allowance" of 8% for officers and 23% for enlisted is proposed to account for a portion of quarters, subsistence, medical care and commissary costs not included in the standard rates.

In providing a source of manpower costs by grade, CSR offers a measure of refinement not available in the NARM. However, no allowance is made for training costs. It will therefore be necessary, when these rates are used for virtually any purpose, to include supplementary estimates of training costs in order to achieve at least the scope of coverage represented by the NARM.

II.1.3. OASD (Comptroller) Military Manpower Cost Reports

Approximately once every two years, the Office of the Assistant Secretary of Defense (Comptroller) issues reports on the costs of military and civilian manpower in the Department of Defense. The most recent such report is *Average Cost of Military and Civilian Manpower in the Department of Defense*, December 1977. Previous issues were released in March 1974 and March 1972.

Like the Billet Cost Model, this report attempts to capture all manpower-related costs (by grade) to the U.S. Government, one of which is retirement. However, unlike the present version of the BCM, it includes the non-DOD and tax adjustment costs discussed in Section I.4.14.

Unlike the NARM, the OSD report excludes military instructor and student costs from its measures of training costs. It also excludes a portion of PCS costs which are considered more related to a Unit's function or mission than to manpower *per se*. On balance, costs from this source are more comparable to the BCM than the NARM. As will be observed in Section II.2., the total of these costs exceeds that of the billet costs (due to the inclusion of non-DOD, tax adjustment and higher retirement costs). However, when those elements are removed, the order is reversed by a significant margin.

II.1.4. Sources Excluded

Two other sources of cost information are frequently mentioned in the present context. They are the Visibility and Management of Support Costs (VAMOSC) Management Information System, and the Joint Uniform Military Personnel System (JUMPS). For the following reasons, those sources were not considered directly relevant to the study.

The VAMOSC system collects and reports historical operating and support costs by weapon system, subsystems and components by function and by other categories. VAMOSC-Air uses Composite Standard Rates as the basis of its manpower costs, which are indicated in the study. VAMOSC-Ships uses (or will use) JUMPS for its manpower costs. JUMPS is a centralized and automated military payroll system. As such, its scope is restricted to cash payments to individual service members. It is therefore not a source of manpower cost estimates, although its various derivative and analytic reports should be an extremely valuable source for developing estimates of incentive pay and reenlistment bonuses by rating and grade.

II.2. EMPIRICAL COST COMPARISONS

This section presents the results of estimating enlisted manpower costs of three major weapons platforms using the BCM and the three alternative sources discussed in the preceding section. The platforms are an A-7E Squadron, a DD-963, and an SSN-688. The following data are based on manpower authorization documents applicable to each:

Table II.2-1
AUTHORIZED MANPOWER

	A-7E	DD-963	SSN-688
E-9	2	—	1
E-8	4	2	3
E-7	8	14	10
E-6	32	33	27
E-5	60	49	26
E-4	58	75	29
E-3	77	85	22
E-2	—	—	—
E-1	—	—	—
TOTAL	241	258	118

Note: Designated Striker positions are included as E-3's.

The BCM estimates have been developed using the full information available; i.e., costs by rating and grade matched with authorization by rating and grade[1]. The OSD and CSR costs are available only by grade, and have been applied directly to the manpower distributions in the preceding table. Cost estimates from those two sources - for FY77 - are shown below.

Table II.2-2
NAVY MANPOWER COST ESTIMATES

	OSD	CSR
E-9	$30,530	$24,466
E-8	25,566	21,340
E-7	23,533	18,636
E-6	20,190	15,997
E-5	16,833	13,346
E-4	14,569	11,168
E-3	12,956	9,951
E-2	12,210	9,127
E-1	11,594	8,284

Recall that the OSD numbers include non-DOD and tax adjustment costs, as well as retirement costs estimated as 39% of base pay. CSR includes none of those nor any allowance for training costs. The CSR estimates above consist only

[1]The BCM estimates were taken from a run of the billet model dated April 26, 1977 and designated as FY77. The base pay tables conform to the official 1977 tables published by OASD (Comptroller). Retirement costs appearing in this run are not consistent with the model's preferred method described in Section I.4.

of the standard rates, the 23% overhead allowance, and an additional $560 per year as an estimate of PCS cost. (That is the PCS factor used in the NARM.)[2]

For FY77, the NARM used a single enlisted MPN average cost of $9,248. However, as discussed in Section II.1.1., that model currently uses two averages, one for direct and the other for indirect/support manpower. In order to follow the current procedures to the extent possible, the following (interpolated) values have been applied here:

Direct MPN:	$9,339
Indirect MPN:	8,884

To obtain NARM costs, first the direct cost factor is multiplied by the total manpower requirement for each platform shown in Table II.2-1. The weighting factor described in Section II.1.1. is then applied to that result. Weights currently used by the NARM are:

A-7E:	1.012
DD-963:	.947
SSN-688:	1.109

Finally, the model's indirect support cost factors and methodology are used to generate estimates of the following costs (reference Appendix E):

- Base Operating Support
- Training
- Health Care
- Personnel Activities
  - PCS
  - Recruiting & Examining
  - Transients
  - Holding Accounts

[2]The figure of $560 applied to FY77. The PCS cost factors and all other factors appearing in Appendix E apply to FY79.

II.2.1. A-7E Squadron

Manpower cost estimates for an A-7E squadron are shown in the table below. They are arrayed at four different levels of aggregation. In terms of the elements included, all sources are comparable at the lowest level, three at the next lowest and two at the level above that.

Table II.2-3
A-7E MANPOWER COST ESTIMATES
(millions of FY77$)

	Source			
Level of Aggregation	OSD	BCM	NARM	CSR
Tot. + Non-DOD + Tax Adjust.	$3.854	—	—	—
Total	3.644	$3.348	—	—
Tot. - Retirement	3.008	3.241	$3.303	—
Tot. - Retirement - Trng.	2.926	3.032	2.898	$3.010

Note that the OSD estimates are higher than the BCM's even when non-DOD and tax adjustment costs are removed. This is attributable to higher retirement costs, a fact revealed at the next lower level of aggregation. There the NARM costs are highest, although only some 2% greater than the BCM. The relative magnitude of the NARM's training cost estimates is revealed at the final level where that model is lowest of all. The BCM tends to be slightly higher than the rest, principally because as a long-run model it treats the entirety of any given cost element as variable, whereas the other models regard a portion of some elements as fixed. Note, however, the difference between the lowest and highest estimate is less than 5%.

II.2.2. DD-963

Cost estimates for the DD-963 are shown below:

Table II.2-4

DD-963 MANPOWER COST ESTIMATES
(millions of FY77$)

Level of Aggregation	Source: OSD	BCM	NARM	CSR
Tot. + Non-DOD + Tax Adjust.	$4.068	—	—	—
Total	3.845	$3.477	—	—
Tot. - Retirement	3.176	3.362	$3.380	—
Tot. - Retirement - Trng.	3.083	3.246	2.946	$3.169

The pattern here is identical to that of the A-7E squadron. The only notable difference is that at the lowest level, the BCM estimate now exceeds the NARM's by some 10%. This may be due in large part to a faulty weighting factor for this ship class. The weight is .947 (the same, incidentally, as for the DD-931 and DD-945 classes). Assuming the factor is intended to represent qualitative differences in manpower requirements, i.e., the grade distribution relative to some norm, .947 seems low. The average CSR cost for the A-7E squadron is $12,490. For the DD-963, it is $12,283. Assuming the 1.012 factor for the A-7E is reliable, the CSR averages suggest the DD-963 factor should be on the order of .995. That would bring the BCM/NARM ratio in line with the first example.

II.2.3. SSN-688

Cost estimates for the SSN-688 are:

Table II.2-5

SSN-688 MANPOWER COST ESTIMATES
(millions of FY77$)

	Source			
Level of Aggregation	OSD	BCM	NARM	CSR
Tot. + Non-DOD + Tax Adjust.	$2.036	—	—	—
Total	1.927	$1.797	—	—
Tot. - Retirement	1.587	1.727	$1.724	—
Tot. - Retirement - Trng.	1.551	1.617	1.526	$1.597

Again the pattern is the same. The only pertinent comment not already made is that the NARM MPN factors reflect actual manning costs. This is in contrast to the other sources where it is assumed all billets are manned at full authorization levels. As a practical matter, that assumption is never entirely valid. For a quantitative insight into this issue, consider the data in the following table.

Table II.2-6

ANALYSIS OF ACTUAL VS. FULLY-AUTHORIZED MANPOWER COSTS

	Avg. CSR Less O'head & PCS (1)	NARM Direct MPN (2)	NARM Weights (3)	NARM Wtd. Avg. MPN (4)	(1) ÷ (4)
A-7E	$9,698	$9,339	1.012	$9,451	1.026
DD-963	9,530	9,339	.995	9,292	1.025
SSN-688	10,709	9,339	1.109	10.359	1.034

The underlying rationale here is that average CSR rates, less overhead and PCS allowances, are directly comparable to NARM average MPN rates. Applying NARM weighting factors to the direct MPN rates (using .995 for the DD-963 rather than the earlier .947) and dividing those results into the CSR rates produces the ratios shown in the right-hand column. The indication is that, at least for the cases considered here, manpower cost estimates which assume full authorization tend to be some 3% higher than those reflecting actual manning levels.

II.2.4. Training Costs

A comparison of NARM, BCM and OSD training cost estimates is presented below. Inasmuch as the BCM's estimates for FY78 include student pay and allowances while those for FY77 did not, both sets of data are shown. (Recall that the FY77 numbers were used in the preceding calculations.)

Table II.2-7

ALTERNATIVE TRAINING COST ESTIMATES
(thousands of dollars)

	NARM					
	MPN	O&MN	Total	BCM (FY77)	BCM (FY78)	OSD
A-7E	$325	$81	$406	$209	$388	$82
DD-963	347	86	433	116	434	92
SSN-688	159	39	198	110	195	35

Shown (for the first time) is the breakout of NARM training cost estimates between MPN and O&MN. Note that more than three-fourths of the NARM's estimate consists of instructor and student MPN. Note also that the OSD estimates are virtually identical to the NARM O&MN costs. The BCM costs are, as expected, both interesting and perplexing. First, the FY77 numbers reflect the model's sensitivity to the relationship between skill requirements and training costs. Total training costs are roughly the same for the DD-963 and SSN-688, despite the fact that 258 billets are authorized for the former and 118 for the latter. Per capita training costs for nuclear powered submarine manpower would be expected to indeed be higher than for conventionally powered surface ships. However, that difference is virtually eliminated when the FY78 school costs are used. The dramatic increase in the DD-963 is attributable in part to what is roughly an across-the-board doubling in costs between the two sets of estimates, and in part to a few rating/grade combinations which show very large cost increases. A representative sample of those combinations appears below, together with the number of each authorized for the DD-963.

Table II.2-8

SELECTED BCM TRAINING COST ESTIMATES: FY77 VS. FY78

Rating/Grade	DD-963 Auth.	FY77 Cost	FY78 Cost
BM : E-3	31	$ 212	$1,478
FTM : E-3	3	2,953	6,674
STG : E-6	3	784	4,462
E-5	4	797	3,134
E-4	5	858	2,620
E-3	5	858	2,620

The differences shown above are certainly not explainable by the inclusion of student pay and allowances, which is reportedly the only change in procedure reflected in the FY78 numbers. Hence, these results tend to reinforce the concerns expressed in Section I.4.7. over the reliability of the system which generates the BCM's school cost estimates.

II.2.5. Retirement Costs

A comparison of OSD and BCM (FY77 and FY78) retirement costs is presented below. As discussed in Section I.4.10., the FY78 estimates reflect the BCM's preferred method of calculating these costs, while the FY77 numbers (used in the preceding comparisons) are based on an interim method. The relationship between those, and their relationship to the OSD results, is of interest.

Table II.2-9

ALTERNATIVE RETIREMENT COST ESTIMATES
(thousands of dollars)

	OSD	BCM (FY77)	BCM (FY78)
A-7E	$636	$107	$142
DD-963	669	115	135
SSN-688	340	70	77

Differences between the OSD and BCM estimates are striking. In comparison to the OSD's flat 39% of base pay, the BCM's figures averaged about 7% in the

FY77 run, and around 9% in the preferred (FY78) version. These results, however, are highly sensitive to the assumptions which underlie the calculations. The OSD approach assumes a 1% real wage growth and a 2% real interest/discount rate. In the FY78 BCM calculations, it was assumed there would be no real wage growth, and the streams of retirement payments were discounted at 6.5% to determine the annuity present values on which the annual cost estimates are based. Additional computations examined during the study suggest that, with a consistent set of assumptions, there would be far less divergence between the two approaches. In Table II.2-10, the BCM's method is reproduced (approximately) for one rating (AB), comparing the effects of alternative discount rates. The President's Council of Economic Advisors presently recommends use of a 1.5% real wage growth and a 2.5% discount rate for analyzing Government-funded retirement programs.[3]

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[3]Federal Register, Vol. 42, No. 224, November 21, 1977

TABLE II.2-10

BCM RETIREMENT COST METHOD
EFFECTS OF ALTERNATIVE DISCOUNT RATES
(Data are for the AB Rating)

Year	Annual Cost 10% Discount Rate	Annual Cost 6½% Discount Rate	Annual Cost 2% Discount Rate
1	$ 39	$ 85	$ 253
2	49	105	316
3	49	106	319
4	103	221	665
5	235	503	1,511
6	247	530	1,590
7	251	537	1,614
8	255	546	1,638
9	259	553	1,663
10	262	561	1,687
11	405	867	2,604
12	513	1,100	3,302
13	644	1,379	4,142
14	659	1,411	4,238
15	674	1,444	4,337
16	714	1,528	4,590
17	781	1,673	5,025
18	855	1,832	5,501
19	936	2,005	6,021
20	1,025	2,195	6,592
21	959	2,147	6,679
22	958	2,156	6,732
23	910	2,113	6,755
24	873	2,103	6,913
25	852	2,092	6,971
26	846	2,084	6,959
27	843	2,079	6,955
28	841	2,078	6,959
29	809	2,022	6,826
30	759	1,929	6,604

II.3 USES AND LIMITATIONS

The foregoing discussion and computational results have demonstrated several things. First, where it is appropriate to exclude training, retirement, non-DOD and tax adjustment costs from an analysis, there are four sources of manpower costs which produce roughly comparable results - when aggregated at the total weapons system level. However, it is difficult to conceive of an analysis involving manpower where training costs are irrelevant. The absence of these costs in Composite Standard Rates is therefore a severe limitation of that source.

The absence of retirement costs in the NARM (and in CSR) is likewise a limitation, although perhaps not as severe since many decision analyses within the Navy are specifically constrained to exclude retirement costs. The NARM's major weakness, at least in the context of this study, is its inability to differentiate between occupational classes and grades. Virtually any trade-off or other weapon system development analysis involving manpower would require that capability to some degree. The NARM is therefore primarily useful for Navy programming purposes, although certain of its features might be profitably combined with other sources of manpower cost estimates. This idea will be developed in the final section of the report.

Except for its inability to discriminate between occupational classes, the OSD source would seem to satisfy all other requirements. However, because of that limitation, because of the very rough method it uses to estimate retirement costs, and because of the somewhat sporadic availability of its estimates, placing heavy reliance on that source does not seem wise.

An inescapable conclusion from all of the above is that some version of a billet cost model - actually two versions - is where the answer lies. A clear need exists for a soundly developed and all-inclusive set of cost estimates which are rating and grade specific. An equally clear need exists for a set which is not as specific. The best approach for satisfying this latter need is through development of "generalized" billet costs along the lines described in Section I.5.3. The Recommendations section of the report will have more to say concerning organization, preparation, documentation and control of billet cost estimates.

PART III:

SUMMARY OF FINDINGS AND RECOMMENDATIONS

III.1. FINDINGS

III.1.1. Billet Cost Model: Specific Findings

Findings relating to the Billet Cost Model are sumarized in two parts. The first is organized around the six specific study objectives cited in Section I.1:

(1) Fixed, variable and marginal costs - For the most part, the Billet Cost Model reflects costs which vary with small changes in manpower; i.e., it is a marginal cost model. There are, however, two notable exceptions to that rule. A considerable share of school costs consists of overhead and other training support which vary only with substantial changes in manpower. And, several components of Constant Cost/Grade and Constant Cost/Year also fall in the same category.

(2) Underlying data and economic relevance - The above discussion bears to some extent on this point. In addition, some of the model's input cost data were found to be non-existent (Proficiency Pay), or to be based on historical experience not relevant to the estimation of future costs (Reenlistment and Settlement Cost.) Further, the model's expected value estimates of hazard pay are not relevant to economic decisions, and the same is true of FICA costs, at least under certain circumstances. Finally, there is evidence that the BCM's underlying data may reflect price levels associated with three different fiscal years.

(3) Allocation of training costs - The BCM's training cost estimates were found to be of questionable reliability. This is apparently due more to

the input data than the method used for allocating those costs. However, that method relies heavily on a set of artificial man-year statistics computed from continuance rates, and on the continuance rates themselves, both of which frequently exhibit erratic behavior. It is doubtful that the merits of that particular allocation scheme are sufficient to outweigh the empirical difficulties associated with it. There was also an arithmatic or programming error detected in the allocation method. It has the effect of systematically understating costs, although that can be easily remedied.

(4) Continuance rates - Problems with continuance rates are mainly attributable to deficiencies in the inventory and transfer data from which they are estimated. Hedges and corrections are employed to guard against implausible values of empirically estimated continuance rates. The model's documented procedure of "smoothing" several years' rates has been abandoned in favor of ratios based on a single pair of integers. Without an improvement in the quality of continuance inputs, the very detailed structure used and generated by the model is not meaningful.

(5) Retirement cost methodology - There is one aspect of retirement cost estimation not recognized by the BCM's present methodology; namely, that once a service member reaches retirement eligibility, the retirement cost attributable to him in any year thereafter is simply the amount by which the expected value of his retirement annuity increases in that year. Prior to eligibility any of a large number of methods is acceptable, provided the amount of the annuity earned at initial vesting has been fully accrued. The method recommended for adoption in the model closely parallels the present method for LOS 1-20.

(6) Costs by program element - The BCM does not have the ability to reflect annual costs by program element (e.g., 81112N - Specialized Training, 81212N - Medical Centers, etc.) That, however, is not a major disadvantage. It would be useful though for the model's documentation to identify those program elements (and appropriations) which constitute the base from which components of Constant Cost/Grade and Constant Cost/Year are estimated. And, because many Naval manpower cost analyses are specifically constrained to exclude all non-Navy costs, the BCM's general utility could be increased if those components were separately broken out.

III.1.2. Billet Cost Model: General Findings

Although costs by rating and grade are the most important products of the Billet Cost Model, the model employs a method of generating grade costs (transferring a single LOS cost on the basis of median service length in grade) which is unsound. Where LOS distributions within grade are asymmetric, or where there is significant year-to-year variation in costs, this can produce unrepresentative cost estimates.

Costs incurred in the first year of service (meaning E-1 and E-2) are largely of an investment or start-up nature. However, the model makes only a minimal attempt (through forward spreading of school costs) to "capitalize" those costs into higher grades. The effect of such a capitalization is not large - typically less than 10% - and can be achieved by any of a number of acceptable methods.

The BCM's overall usefulness could be increased substantially in two ways. First is through improved documentation. The present documentation is

both outdated and incomplete. Its description of several key elements - training, retirement and down costs - is no longer applicable, and it provides very little explanation of the data sources and computational methods used to generate the remaining cost estimate.

A second and highly useful enlargement would take the form of "generalized" billet costs. Although manpower requirements frequently cannot be defined by rating and grade, a need remains for cost estimates that reflect some sensitivity to occupational classes and skill/experience levels. Given a meaningful set of categories into which the ninety-odd ratings can be collapsed, and given also a correspondingly smaller set of "ranks," statistical computation of generalized billet costs is quite straightforward. Candidates for each are proposed in the report.

III.1.3. Other Sources of Manpower Costs

When training, retirement, non-DOD and tax adjustment costs are excluded, four sources of manpower costs - Composite Standard Rates (CSR), the Navy Resource Model (NARM), OASD (Comptroller) reports, and the BCM - produce roughly comparable results when aggregated at the weapon system level. However, none of these is entirely adequate for use in applications where manpower requirements cannot be defined by rating and grade.

The absence of all of the above-named cost elements from CSR - particularly training costs - is a severe limitation of that source. The NARM's inability to differentiate between types or levels of manpower is its major weakness insofar as weapon system design trade-offs are concerned. OASD estimates are insensitive to different types of manpower; its retirement cost

methodology is very coarse; and the results are only sporadically available. Billet costs generalized across ratings and grades offer the most promise.

III.2. RECOMMENDATIONS

A summary of remedial actions recommended for the Billet Cost Model appears in Section I.6. Rather than repeat those here, the reader is referred to that section. However, one additional piece of summary material is contained in Table III.2-1. That table presents, for one rating and grade, a comparison of the BCM's present cost elements and estimates with those recommended by this study.

The central recommendation of the study is that emphasis be shifted away from the Billet Cost Model, as such, and placed instead on an official Billet Cost Report which would be prepared annually. There should be a BUPERS Project Officer responsible for ensuring thoroughness and quality control in the input data, computations and final documentation. The report would consist of three major sections: (1) text, (2) marginal cost estimates, and (3) average cost estimates.

The text would describe completely how the report's estimates are developed, with sufficient detail concerning data sources and computational methods to permit a user to reproduce the estimates. In addition, the rationale, assumptions and limitations of the estimates would be discussed in the text in such a way as to minimize the likelihood of their being misinterpreted and/or misused.

There would be two sets of marginal cost estimates, one by rating and grade and the other generalized across ratings and grades. Procedures

TABLE III.2-1

COMPARISON OF PRESENT VS. RECOMMENDED
BILLET COST ESTIMATES:
AB RATING, GRADE E-9

Element	FY78 BCM	Recommended Estimates w/o Hazard Pay	Recommended Estimates with Hazard Pay
Base Pay	$15,790	$15,818[1]	$15,818
Hazard Pay	-0-	-0-	1,260
FICA	955	957	1,033
Constant Cost/Grade	4,863	3,290[2]	3,290
Proficiency Pay	-0-	-0-	-0-
Constant Cost/Year	1,579	1,092[3]	1,092
School Cost	231	95[4]	95
Reenlist./Settle. Cost	-0-	-0-	-0-
Retirement Cost	1,831	3,968[5]	3,968
Non-DOD Cost	——	629[6]	629
Tax Adjust. Cost	——	1,088[6]	1,088
Capitalized Start-up Cost	——	1,239[7]	1,239
Total Cost	25,249	28,176	29,512
Down Cost	710	812[8]	850
Billet Cost	$25,959	$28,988	$30,362

[1] Weighted-average, based on LOS distribution within grade

[2] Excludes Commissary, Govt. Qtrs.-Imputed, and ½ of Medical/CHAMPUS costs

[3] Excludes Command & Administration and Dependent School Costs

[4] Estimated by method described in Appendix C, with (T-S) based on recommended estimates rather than BCM

[5] Weighted-average, based on LOS distribution within grade. Year costs estimated by "Obligations Level Interpolation" method described in Appendix D, with discount rate equal to .02.

[6] Taken from Dec.'77 OASD Report; escalated by 1.06 to FY78 price level

[7] Estimated by method described in Sec. I.5.2, with (T-S) based on recommended estimates rather than BCM

[8] Estimated by method described in Sec. I.4.12., with A equal to BCM rate of .972

for developing those estimates have been recommended at various places throughout this report. Also, to increase the utility of the Billet Cost Report, all non-Navy costs should be aggregated or at least made visible so that total billet costs, net of those amounts, would be available for use in analyses specifically constrained to exclude retirement, other DOD and non-DOD costs.

To further increase the utility of the report, there should be a section containing estimates of average costs - again both for billets and generalized billets. First, many of the same analyses which exclude all non-Navy costs are also constrained to reflect the "full" costs of Naval manpower. This essentially means average costs. However, these measures are useful not simply as a means of satisfying administrative requirements. Many important decisions - even trade-off decisions - can ultimately involve large quantities of manpower. (The Navy often buys in bulk.) In those cases certain costs which were described earlier as being invariant with marginal billet changes - notably the "support staff" costs associated with training, hospitals, etc. - become relevant to the decisions. The problem becomes one of estimating the cost consequences of incremental rather than marginal changes, and if the increments are large enough, average costs are better estimators than marginal ones. The NARM's support cost methodology, described in Appendix E, provides a set of factors or multipliers that could be used, at least as a first iteration, to "inflate" the report's marginal costs to average costs.

Finally, there is a considerable amount of manpower cost information that could be usefully appended to the Billet Cost Report. Examples are:

representative manning authorizations for selected weapon system types, tables of retirement cost estimates with alternative discount rates, and OSD-approved indices for price level adjustments. The general idea is for the report to serve the needs of a broad community within the Navy, and yet to do so without compromising analytical structure or empirical detail.

APPENDICES

APPENDIX A

BCM SCHOOL COST ALLOCATION ERROR

In analyzing the Billet Cost Model's algorithm for allocating school costs, an error was deteced which has the effect of systematically understating costs. The algorithm and its error are described and the necessary correction indicated.

School costs are based on inputs U_i and I_i which represent, respectively, total school costs and manpower inventories for year "i." These are used to obtain values $R_i = U_i \frac{\Sigma\ AVG_i}{\Sigma\ I_i}$ which scale inputs up or down so that

$$R = \Sigma R_i = (\Sigma\ AVG_i) \frac{\Sigma\ U_i}{\Sigma\ I_i}$$

is the product of BCM 'model' man years realized for a cohort times the school cost per man year reckoned from the input data.

Values R_i are used to produce smoothed costs per man year, C_i, which are given by

$$C_1 = \frac{AVG_1}{AVG_1 + AVG_2} \cdot \frac{R_1}{AVG_1} + K$$

$$C_i = \frac{AVG_i}{AVG_i + AVG_{i+1}} \cdot \frac{R_i}{AVG_i} + \frac{AVG_i}{(AVG_{i-1} + AVG_i)} \cdot \frac{R_{i-1}}{AVG_{i-1}} \quad , \quad i > 1$$

K is an initial cost inserted by the program. To preserve costs (after the initial rescaling), it is necessary that

$$\Sigma AVG_i\ C_i = AVG_1 \cdot K + R \quad ,$$

(although, depending on how K is defined, the leading term might appear as N_0K where N_0 personnel enter at cost K each).

However,

$$\Sigma AVG_i \cdot C_i = AVG_1 \cdot K + \frac{R_1}{AVG_1 + AVG_2}\left(AVG_1 + \frac{AVG_2^2}{AVG_1}\right) + \frac{R_2}{AVG_2 + AVG_3}\left(AVG_2 + \frac{AVG_3^2}{AVG_2}\right) + \ldots$$

Since $AVG_i \geq AVG_{i+1}$ (and, ordinarily, the inequality obtains)

erms in parentheses obey

$$AVG_i + \frac{AVG_{i+}}{AVG_i} \leq AVG_i + AVG_{i+1}$$

Thus each R_i in the sum is multiplied by

$$\frac{AVG_i + \frac{AVG_{i+1}^2}{AVG_i}}{AVG_i + AVG_{i+1}} \leq 1.$$

The inequality obtains ordinarily, so that costs are lost.

Rewriting the recursion so that

$$C_i' = \frac{AVG_i}{AVG_i + AVG_{i+1}} \cdot \frac{R_i}{AVG_i} + \frac{AVG_{i-1}}{AVG_{i-1} + AVG_i} \cdot \frac{R_{i-1}}{AVG_{i-1}}$$

and the lagged term is multiplied by AVG_{i-1} instead of AVG_i restores the balance:

$$\Sigma AVG_i\ C_i' = AVG_1 \cdot K + R.$$

This is probably what was intended.

APPENDIX B

EXAMINATION OF BCM SCHOOL COST INPUTS FOR THE AB RATING

An effort was made to disaggregate and assess the school cost input for the Aviation Boatswain's Mate (AB) rating in LOS 1. That is a general rating which contains three service ratings:

ABE - Launch and Recovery Equipments,

ABF - Fuels,

ABH - Aircraft Handling.

For LOS 1, the AB value is equal to the sum of the costs of the three service ratings. Those data, taken from the most recent BCM run available (3 April 1978), are:

Rating	Cost (mil)	
ABE	$1.523	
ABF	1.638	
ABH	3.954	
AB		$7.115

Indications are that these numbers apply to FY76, although no official acknowledgment of that could be found.

The objective was to determine whether the costs are, in rough terms, consistent with other estimates developed independently. The bulk of AB training in year one consists of "A" school which, in most cases, follows recruit training. The data below were obtained from the Enlisted Rating Control Officer for AB's:

Rating	Approx. LOS 1 "A" School Output FY76	Approx. Duration of Course
ABE	209	1.8 mo.
ABF	224	1.0 mo.
ABH	276	1.3 mo.

A rough estimate of $1600 per student-month (which contains some elements omitted from the BCM calculations) was obtained from CNET, Pensacola. Combining that with the above data results in a total of $1.534 million.

The balance of AB schooling in LOS 1 consists mostly of a Damage Control and Fire Fighting (DC/FF) course. The BCM's separate estimate of that was substantially less than $1 million. Thus, there is some $5 million of the model's estimate of $7.1 million that is unaccounted for. There is some indication that several million dollars of costs associated with the DC/FF course might have been improperly assigned to this rating. That, however, is speculative. In any event, what these results suggest is that it would not be prudent to accept without further question the school costs used as input to the Billet Cost Model.

APPENDIX C

A SIMPLIFIED METHOD OF ESTIMATING SCHOOL COSTS

The procedure described here consists of two steps. Step 1 involves estimation of the cost of training directly associable with each grade; i.e., "unallocated" school costs. In view of the recommendation elsewhere in the report that the totality of E-1 and E-2 costs be capitalized, estimation begins with grade E-3. In Step 2 the cost estimates are allocated, in part to the directly associable grade and in part to the next higher grade. The relationships are as follows, and are understood to apply to a specific rating:

$$C_j^1 = \sigma_j (T_j - S_j)$$

$$C_j^2 = \frac{N_j C_j^1}{N_j + N_{j+1}} + \frac{N_{j-1} C_{j-1}^1}{N_{j-1} + N_j} .$$

where,

C^1 = unallocated school cost estimate

C^2 = allocated school cost estimate

σ = fraction of billet years spent in school

T = total cost from BCM (col. 12)

S = school cost from BCM (col. 8)

N = total billet strength

j = grade

The central premise of this method is that the only marginal cost of training is the cost of the student himself. This is at best an approximation of reality, but if one reflects on the true nature of a marginal change, it is apparent that little else is altered except the flow of funds necessary to pay and support the trainee.

The allocation procedure employed recognizes that the objective of training is twofold: (1) to develop skills required in the current grade; and (2) to lay groundwork for advancement to a higher grade. Total associable cost in any grade, $N_jC_j^1$, is allocated uniformly over that grade and the next higher grade. A property of the procedure is that $\Sigma N_jC_j^1 = \Sigma N_jC_j^2$; that is, total costs actually observed equal total allocated costs.

As an illustration of this method, consider the following data which apply to the RM rating:

Grade	T-S (1)	σ (2)	N (3)
E-3	9,513	.016	2,708
E-4	11,339	.069	3,707
E-5	14,434	.032	4,092
E-6	18,414	.016	2,730
E-7	21,057	.010	1,450
E-8	22,631	.008	369
E-9	24,296	.006	149

Data in column (1) were taken directly from the BCM. Data in columns (2) and (3) were taken from the Enlisted TPS&D report, a MAPMIS product, for Fiscal 1977. Example estimates are:

$$C_3^1 = .016(9{,}513) = \$152$$

$$C_4^1 = .069\ (11{,}339) = \$782$$

$$C_4^2 = \frac{3{,}707(782)}{3{,}707 + 4{,}092} + \frac{2{,}708(152)}{2{,}708 + 3{,}707} = \$436$$

The full sets of unallocated and allocated cost estimates are shown below.

Grade	C^1	C^2
E-3	$152	$ 64
E-4	782	436
E-5	462	649
E-6	295	470
E-7	211	361
E-8	181	297
E-9	146	275

Note that $\Sigma N_j C_j^1$ = $6.401 million and $\Sigma N_j C_j^2$ = $6.402 million, with differences due to rounding.

APPENDIX D

RETIREMENT COSTS*

I. Introduction

A. Overview

Five methods are available for calculating annualized retirement costs in the billet cost model. It is stated that three or four dozen alternatives have been suggested.

Since retirement costs are not small, however they might be distributed over the service career, any method of distributing them is bound to create controversy. But retirement costs are surely part of the costs of services provided by personnel, to be considered in any tradeoff that includes them, whether it is a weapons system tradeoff or some other kind.

The billet cost model can't be faulted for failure to confront this simple fact. Nor should it be faulted for offering a variety of ways in which to trace the implications of this fact. The 'model' is a service bureau -- in operation, and with operating procedures -- for the supply of estimates of many kinds of costs, defined (or definable) by its customers. Except as, by fiat, all customers can be made to settle for a uniform product, there is no way to make the product uniform and no particular use in making it so. The end result of this examination of methods is that more variety is needed, but, for weapons system costing, variety of a circumscribed

*This appendix was prepared by John E. Berterman, Principal of J. Watson Noah Associates, Inc. It originally appeared in the study's Interim Report, and is reproduced here in its entirety.

kind -- following the retirement pay schedule where it exists, interpolating before it does.

B. Contents

There is a need to examine the annual retirement costs now provided for what they are. They look a little odd, especially in the period after retirement entitlement is vested. Section II discusses this and the standard by which they are indeed odd — the accrual of retirement entitlements over the service career. Section II goes on to indicate why this accrual pattern, interpolated over the period before vesting, offers the kind of retirement cost assignment most clearly consistent with the objectives of weapons system cost analysis and some other purposes besides.

Section III supplies the actuarial mathematics of interest in simplified -- continuous -- form. Section IV shows application of the assorted methods discussed to data used in producing BCM results.

II. Qualitative Discussion

The variety of methods possible for calculation of retirement costs, and the suggestions made for adding to them exemplify an infinity of ways in which they can be assigned to each year of the active career. All that is necessary is that costs, on average, sum to the retirement payments finally made, when these payments are reckoned as an annuity principal. More or less emphasis can be laid on the requirement that any current balance, in an overall account of funds available for pay-out, should be in excess of imminent payouts.

Boundaries are placed on these methods by two extremes. The first is to assign all retirement cost to the instant of retirement. Such pay-as-you-go funding is bettered in practice by putting the retiree on a payroll which is met out of operating revenues. This is just what is done, and it is optimum financial management in postponing outlays until they fall due. But the cost assigned to each year of the active career -- zero -- is inane as a way of describing how service in particular career years and particular grades generates retirement cost.

One might note, however, that for the purpose of predicting annual new retirement costs, such a method of accounting is admirably direct and better than any other. The persistence in the future of experienced continuation rates (or any others used in place of them) casts doubt on any such prediction, of course. For the far enough future, enlistment rates yet to be seen evidently degrade predictions even more. But exactly the same contributors to uncertainty underlie the use of any other accounting procedure in producing such predictions. And any other accounting procedure begs the question of just what it is predicting and for when.

The opposite pole of accounting method is, of course, to assign the average retirement cost per recruit to the instant of entry into the Navy. Then 'surpluses' generated by retirements with no cost, or any other cost below the average, can be transferred to the accounts of personnel still in service. For large enough groups, there are no additional annual costs or savings. Imaginably, a powerful union of entrants might enforce such an advance deposit procedure on an employer who threatens to go belly up sometime soon, even though his cash position will let him place the required

deposits with a trustee. Not surprisingly, the conjunction of circumstances needed for this kind of funding doesn't emerge in employment by the guarantor of all imaginable trustees, or any other. But it is the opposite pole of accounting method -- pay in advance. It is as inane as pay-as-you-go in associating annual retirement cost with service. All cost is incurred in the recruitment year. Again, the cost assigned to most years is zero.

For prediction, the method yields only the retirement cost per year of a steady state Navy with a steady state recruiting policy -- the enlistment rate is multiplied by the deposit per enlistee. Equivalently the size of such a Navy is multiplied by this deposit and divided by the average career length. As a prediction, this is scarcely interesting; but as a description of possibilities for the long run in configuring the Navy, the measure itself has merit. The method, absurd or not, yields the same values for it as any other method when common structures are assigned to continuation rates.

The first method never shows a surplus over accounts now payable. The second never shows a balance below accounts expected to become payable. Neither one concerns itself at all with the process by which obligations are accrued. Most actuarial methods are compromises between these poles of accounting, even when they 'individuate' accounts, as can always be done. Effectively, they introduce a constraint that expected outlays (taking into account the distribution of retirement times) have been 'funded' by costs charged to preceding years of service. They conceive the pension fund as a band which has only to meet claims as they occur. It does not have to be prepared, at all times, to meet all outstanding claims. The annual costs assigned to each year of service have only to yield a surplus over the payments made, which falls

to zero when all are made.

In late career years, as the number of individuals shrinks to whom costs can be 'charged,' the annual costs tend to rise, as retirement entitlements reached in earlier years still remain to be 'paid' for in keeping the books in balance.

Thus the costs assigned bear only peripheral relation to the accumulation (or decay) of retirement entitlements over the career. They derive from the conveniences for accounting purposes afforded by each accounting method. Each method yields the same final balancing of the books, but each one assigns a different series of costs by year. Cost structures are such as to contradict simple calculation of, for example, the retirement benefit accrued in the twenty-fifth year of service.

This fine-structure *difference* is unimportant in rating career averages and the like, by virtue of the balancing of the books. Surplus requirements are unimportant, too. For such purposes, any method that balances the books at the end of the career will suffice. Where fine structures tend not to differ -- over the period before retirement rights are vested -- they fill in a conspicuous gap in the problem of assigning annualized retirement costs. At least, these pre-vesting costs are not set to zero, in contradiction of common sense intuition. But these costs still differ from one method to another. And they are colored by the general confusion of payment for some benefits by borrowing benefits from those continuing in service. The methods only give an appearance of solving a nettlesome problem.

Among the methods open in balancing the books is, of course simply following the annual accruals of retirement benefits to which personnel are entitled, independently of whether or not they retire, or whether it is an actuarially

safe bet that they won't. This is simple for the period after vesting, although it leaves open the problem of interpolating costs over the period before vesting. The procedure corresponds to the full funding of pensions by simply following obligations accrued. The retirement cost of service in the twenty-fifth year is just the amount by which the entitlement changes in that year. It can even be negative for late years, as the effect of reduced life expectancy overtakes other factors in the benefit formula.

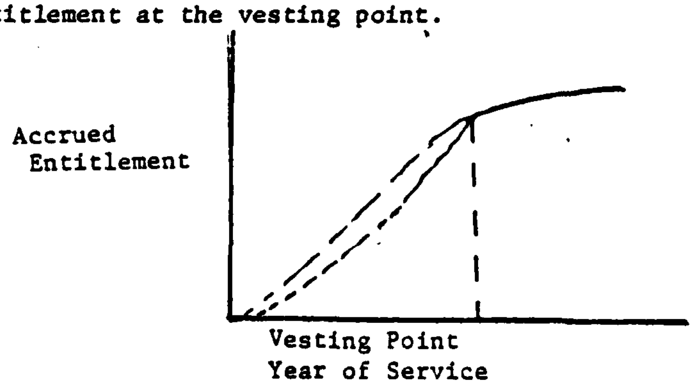
For tracing retirement costs to each year, this treats the accrued obligation as accumulated payment for past service. Then a change in the obligation during a year's service after vesting is the retirement cost of the year's service, just as the change in accrued pay over the year is the wage cost for the year.

What recommends this procedure for weapons system cost analysis is the same set of considerations that call for longevity-specific pay. After averaging, it becomes grade-specific pay. Similarly, longevity-specific retirement pay becomes grade-specific retirement pay. It places the generation of obligations at the skill level where it occurs. In that way, a system utilizing a skill level is charged for the <u>new</u> obligations it incurs in doing so. In essence, it is new obligations that a systems cost analyst is trying to trace — the new obligations generated by a system. The system doesn't inherit unpaid bills or pass them along. The required pattern of funding is an additional and real problem for the analysis, but a distinct one and a consequence of the obligations pattern. Once the timing of obligations crystallizes, this funding pattern can be forecast by application of the funding practices specific to each of its cost generators. Conceivably, for manpower,

it will be found at that stage that personnel will have to be held totally idle, waiting for employment by a particular system. Over such periods retirement (and many other) costs should be charged to the system. But within the terms of the billet cost model, the expression of this effect is in down cost and availability, and not, for example, in base pay per man-year of service. There is every reason, as the model is conceived, not to express the effect in retirement cost. There is no reason to suppose that any accounting practice originating for completely different purposes expresses this effect in the right way. Actuarial noise is only noise. It is not expressive of deep considerations that otherwise escape the model.

In short, the obvious method of annualizing retirement costs, where it can be followed, is most appropriate to systems cost analysis. It is evidently most appropriate, also, to tracing out the real differentials in costs generated by policies directly or indirectly aimed at influencing age distributions. Thus the retirement costs of senior personnel, or the savings available by encouraging their retirement can't be rated in any other way. These costs are assuredly over-rated by the methods offered.

It remains true that such a 'solution' is a simple solution only in the period of service after vesting. Over the period of service before vesting -- where most service occurs -- no definite rule is indicated for assigning annual cost. The datum given is only the sum of these -- the retirement entitlement at the vesting point.



In the sketch above, the solid portion of the curve indicates the

path that can be followed by assigning to each year of service the growth or decline of accrued entitlement as the cost of the year's service. No explicit rule assigns the lump sum vested to service in prior years. The interpolated curves do this by tracing out a virtual accrual which fairs into the vested entitlement. It depicts, for an individual attaining vesting, annual cost accruals of the vested sum. Formally, nothing prevents interpolation by assigning value zero to all of the interval before vesting. In effect, generation of the whole obligation could be charged to the instant of vesting. The higher of the dashed interpolations — the straight line -- is obtained by accruing a level payment for each year of service. The lower of the two is obtained by accruals in proportion to base pay so that the amount vested is, indeed, in proportion to a multiple of pay — an accumulation of deferred wages.

The dashed curves mark the outer limits of an indefinite area of 'reasonable' assignments of the vested principal to service in prior years. The one requirement that might be laid on them is independence of retention rates in the interpolation. The interpolation allocates a vested sum.

Any schedule of annual costs in years prior to vesting which takes retention rates into account -- as it must -- can be reduced to combination with retention rates of an interpolating curve of the kind described. Calculating the implied curve of accrual for the vested individual enables the inspection of a method for reasonableness. Thus costs which emerge from assigning the same fraction of <u>group</u> base pay as retirement cost in each year imply an interpolation which accumulates high costs for the individual in early

years, in inverse proportion to the probability of eventual vesting. This is distinct from an interpolation for the individual of costs which are a fixed proportion of individual pay, not conditioned by the probability of eventual vesting — somewhat more reasonable as a schedule of the process of accrual and certainly simpler.

Each interpolation of accrual progress represents a theory by which operation of a trust fund should proceed in collecting the amounts finally vested as annual payments for labor service. Each imports its own hypotheses and implications. None emerges out of any mathematical necessity generated by the solid graph. Until law, regulation, or fiat closes the problem, there is no one right way to assign annual costs over the period before vesting. There are only more and less reasonable ways. Narrowed to use in only the interpolation problem, available actuarial methods tend to produce reasonable ones. But, as indicated, it is well to examine them for reasonableness in light of their original purpose of simplifying financial management.

III. Mathematical Discussion

A. Introduction and Contents

In what follows, continuous notation is used to show the properties of 'actuarial' methods that have been, or might be, used in calculating retirement costs with billet cost model data. Discounting is not introduced, explicitly, to avoid cluttering formulas.

Section B summarizes notations. Section C shows the infinities of methods useable and some general qualitative effects.

Section D discusses the weighted expectations methods employed now.

Section E discusses methods narrowed to the purpose of assigning costs in the period before vesting that 'fit' the entitlement vested at the vesting point.

Section F discusses a hyperactuarial model of expectations, based on annualizing the effect of present retention decisions on future costs.

Section G lists the methods available for assigning billet costs along with the method orginally suggested for assigning them.

B. Notation

Time t measures longevity in service. The probability distribution

$$F(t) = \int_0^t f(x)dx = 1 - G(t)$$

describes the probability of retirement at, or before, attaining longevity t. f(t) is the density. $G(t) = 1 - F(t)$ is tne probability of attaining longevity in excess of t -- the probability of continuation through time t.

In the terms of the billet cost model, when N_o recruits enter year 1, $N_oG(t)$ enter year t.

Of these, $N_oG(t)r(t)\cdot h$ retire in the interval (t, t+h). r(t) is the retirement rate at longevity t, the continuous reflection of the continuation rate.

$$r(t) = {}^{f(t)}/_{G(t)} \text{ and } G(t) = \exp(- \int_0^t r(x)dx)$$

show the relation between rates and distributions.

Retirement principal P(t) is the entitlement at time t, so that

$$\overline{P} = \xi(P) = \int_0^\infty f(t)P(t)dt$$

is the expected retirement cost (per recruit).

$$\overline{L} = \xi(T) = \int_0^\infty t f(t)dt = \int_0^\infty G(t)dt$$

is the expected longevity.

C. <u>Qualitative Considerations</u>

When the recruiting rate is N recruits per unit time, the expected number of recruits still in service is

$$N \int_0^\infty G(x)dx = N\overline{L}.$$

The expected rate at which retirement costs occur is

$$N \int_0^\infty f(x)P(x)dx = N\overline{P}$$

The retirement cost rate per man in service is then

$$\frac{N\overline{P}}{N\overline{L}} = \frac{\overline{P}}{\overline{L}} = \text{Retirement Cost}/\text{Year of Service}$$

Thus means obtained from the longevity distribution yield a long run rate of retirement cost. From the definitions it is clear that a level charge of $\frac{\overline{P}}{\overline{L}}$ per year for each man in the force will 'fund' retirements.

Advance funding of the amount $\overline{P}$ for each recruit assures no new cost, on average, by virtue of

$$\overline{P} = {}_o\int^t f(x)P(x)dx + G(t)E_t(P).$$

$$E_t(P) = \frac{1}{G(t)}\ {}_t\int^\infty f(x)P(x)dx$$

is the expected retirement principal among those with longevity t of greater. For all t,

$$\frac{\overline{P} - {}_o\int^t f(x)P(x)dx}{G(t)} = E_t(P).$$

The surplus of initial funding $\overline{P}$ over expected payouts through time t is the sum of all expected future payments.

This down-payment exemplifies the infinity of charge schedules adequate to fund retirements on average. Where C(t) is the sum of costs assigned through longevity t, all that is required is that

$$\overline{P} = {}_o\int^\infty f(t)C(t)dt$$

The expected accumulation of costs at time t is then

$$G(t)C(t) + {}_o\int^t f(x)C(x)dx$$

The expected accumulation of retirement payments through time t is

$${}_o\int^t f(x)P(x)dx,$$

so that the surplus of accumlated costs assigned over payments, at

time t, is

$$S(t) = G(t)C(t) + \int_0^t f(x)(C(x) - P(x))dx$$

This surplus -- or deficit -- goes to zero as t goes to infinity under any conditions where C(t) has an expected value. The family of functions C(t) is narrowed -- but still infinite -- by placing on it the side condition that the surplus not be negative -- a deficit.

Examination of the surplus shows that the left term, G(t)C(t) reflects cost accumulations on behalf of the fraction still in service, G(t). On the right, are 'abandonments' of amounts C(x)-P(x) by those retiring at earlier longevity x. The condition of non-negative surplus can be attained by making $C(t) \geq P(t)$ early in the career. Choosing the inequality, so that, indeed, $C(t) > P(t)$ entails, later in the career, $C(t) < P(t)$, in order to maintain

$$\int_0^\infty f(t)(C(t) - P(t))\, dt = 0$$

That is, when some individual accumulations C(t) exceed P(t) -- the retirement payment -- some others must fall below it, for other values of t.

Surplus per man still in service at time t is

$$\frac{S(t)}{G(t)} = C(t) - E_t(C-P)$$

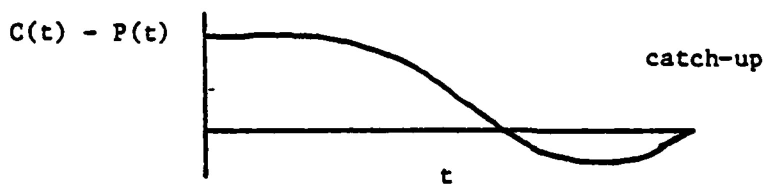
where $$E_t(C-P) = \frac{1}{G(t)} \int_t^\infty f(x)(C(x) - P(x))dx$$

so that, for 'middle' stage retirees, surplus per head can exceed P(t)

even when $C(t)$ does not, by virtue of surplus obtained from earlier retirees, or the same thing, negative expectation, $E_t(C-P)$. Surplus per head can coincide with $P(t)$ over a range of values only as $C(t) - P(t) - E_t(C-P) = 0$ over the range and $C(t) - P(t)$ is constant. That is, there is freedom to accumulate a surplus up through some time t and then use it up for a while, maintaining $C(t) - P(t)$ at a constant level.

In such a case, $C(t)$ remains parallel to $P(t)$ and $C'(t) = P'(t)$. That is, annual charge rates follow annual change in available retirement principals.

When no such procedure is followed, but surplus is only made to cover entitlements for large values of t, then a catch-up of $C(t)$ with $P(t)$ from below is generated



Then C-P is increasing during the catch-up and $C'(t) > P'(t)$. Annual charge rates exceed annual change in available retirement principals.

As far as pay-outs are concerned, there is, of course, only the need to cover principals to be paid in the near future, not to cover exactly each man still in service. This leads to requiring only that $G(t)C(t) + \int_0^t f(x)C(x)dx = \int_0^t f(x)P(x)dx$ or $C'(t) = r(t)P(t)$. This is pay-as-you-go funding.

D. <u>Weighted Expectations Methods</u>

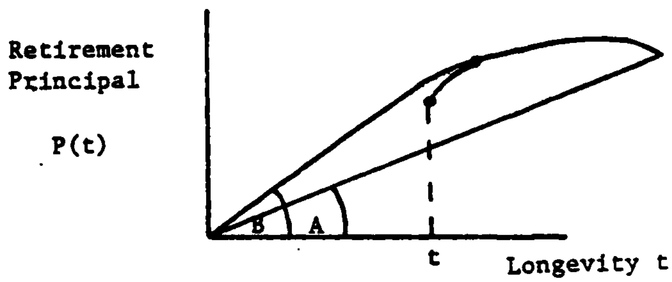
Level funding of the expected retirement benefit at each age -- so that the level is age dependent -- comes, without discounting, to assigning

a charge rate $C'(t)$ which is

$$C'(t) = \frac{1}{G(t)} \int_t^\infty f(x) \frac{P(x)}{x} dx$$

This can be imagined as reflecting the following procedure. At the termination of each career, the retirement benefit is divided in equal proportions over the whole career. Each 'user' of the services rendered, who uses them for time h, will pay h $\frac{P(x)}{x}$ for a retiree at longevity x. The averaging is among those in service at age t — their expected 'final' prices.

With regard to the schedule of benefits, $C'(t)$ is an average slope used to grade costs, in place of $P'(t)$ -- the rate of change in retirement benefits at longevity t.



Thus, at time t, slopes between the tangent of angle A and the tangent of angle B are averaged to produce the cost assignment $C'(t)$, in place of the tangent to $P(t)$ which is $P'(t)$.

This is a smoothing method which supports payouts with adequate inflow to build up reserves against imminent pay-out in the banking sense. Total pay-ins by time t are

$$\int_0^t G(x)C'(x)dx = \underbrace{\int_0^t f(x)P(x)dx}_{\text{Pay-outs}} + \underbrace{\int_t^\infty f(x)P(x) \frac{t}{x} dx}_{\text{Reserves}}$$

The reserve term reflects accumulation of fraction $\frac{t}{x}$ of the retirement principal P(x) for the population (density) to retire at longevity x. As t increases, so does $\frac{t}{x}$ so that the reserve is fully accumulated when t and x become equal.

This instances a general framework in which banking principles can be cast, and most actuarial methods of any interest.

Density d(t/x) is assigned which is zero outside {0,x} and such that $\int_0^x d(t/x)dt = 1$. Using $D(t/x) = \int_0^t d(z/x)dz$, charge rate

$$C'(x) = \frac{1}{G(t)} \int_t^\infty f(x)d(t/x)P(x)dx$$

weights charges with d(t/x) instead of the particular choice $\frac{1}{x}$. Then, at time t, total pay-ins are

$$\int_0^t G(x)C'(x)dx = \int_0^t f(x)P(x)dx + \int_t^\infty f(x)D(t/x)P(x)dx$$

Fraction D(t/x) approaches 1 as t approaches x or vice-versa, so that 'reserves' D(t/x)P(x) are built-up as needed.

The method evidently reflects the kind of financial accounting that might be applied in smoothing annual budgets and has been used to generate a 'normal cost' for Navy retirements — the annual cost, for such a method, that would obtain if the method had always operated.

Another financial method widely applied (although applied with real-life adjustment to real-life pay and population changes) is assigning an annual cost in fixed proportion to pay -- base pay in the billet cost formulation. The annual charge corresponds to

$$C'(t) = \frac{\int_o^\infty f(t)P(t)dt}{\int_o^\infty G(t)w(t)dt} \cdot w(t)$$

where w(t) is pay.

Replacing the pay basis w(t), by 1, converts $C'(t)$ to a constant payment per man-year of service.

Either one of these simplifies calculations based on payrolls, after the actuary has supplied the scaling constant.

E. Pre-Vesting Costs

The funding of retirement benefits ordinarily proceeds independently of who has right to the use of the accumulated funds (or other retirement guarantees) by vesting. And, ordinarily, the retirement option falls open only after some vesting has occurred. Early, or graduated, vesting does make for explicit statement of a funding schedule over the period before the individual can retire, resting often on a schedule of 'proper' payments for an individual who eventually retires. This schedule can be used in combination with retention rates to cut employer costs of funding -- because real obligations are being passed, not accounting transfers.

Using the notation adopted, time T is the time of 'vesting' and is the time at which principal P(T) is accumulated for individuals who are to be vested. The accumulation schedule which the employer must support is $S'(t)$, with $\int_o^T S'(t)dt = P(T)$.

The probability that, at longevity t, longevity T will be attained, is just $\frac{G(T)}{G(t)}$. Just this fraction of the 'proper' payment for the individual serving until time T provides total fund, per recruit, G(T)P(T) at time T. That is,

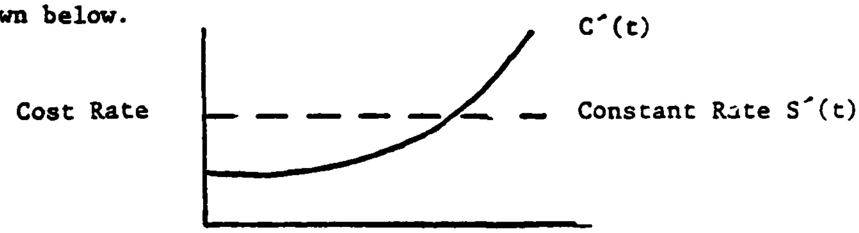
$$C'(t) = \frac{G(T)}{G(t)} S'(t)$$

so that

$$\int_0^T G(t)C'(t)dt = G(T)\int_0^T S'(t)dt = G(T)P(T)$$

Thus, when there is an agreed form for $S'(t)$, the prospective cost rate, $C'(t)$ weights it by factor $\frac{G(T)}{G(t)}$ -- the probability that longevity T will be attained. This factor is near one as t approaches T and smallest for t near zero. The effect of it is to make $C'(t)$ convex relative to $S'(t)$.

Thus, for $S'(t) = \frac{P(T)}{T}$ -- a flat payment per year, $C'(t)$ is curved as shown below.



Similarly, when $S'(t)$ is proportional to $W(t)$, pay in year t, $C'(t)$ will fall below and then above the curve obtained by taking a constant fraction of payroll -- where $C_k'(t) = kS'(t)$, with k chosen to make total payments equal to $G(T)P(T)$.

The first method produces

$$C_1'(t) = \frac{G(T)}{G(t)} \frac{W(t)}{\int_0^T W(x)dx} P(T)$$

The second produces

$$C_2'(t) = \frac{G(T)W(t)P(T)}{{}_o\int^T G(x)W(x)dx}$$

In effect, the first curve recognizes that expected retirement benefit per dollar earned increases from year to year. The second curve proceeds as if it were constant.

The re-shaping effected by applying factor $\frac{G(T)}{G(t)}$ is distinct from the re-shaping generated by financial considerations. Then what corresponds to $S'(t)$ might emerge as, for example, level funding of the pension sum for each year of earning. That is earnings in the first year are funded at rate $\frac{1}{T}$; earnings in the second year at rate $\frac{1}{T-1}$, and so on. The <u>funding</u> accumulation through year t is then, in continuous form,

$${}_o\int^t w(x)\,\frac{t-x}{T-x}\,dx$$

$$= {}_o\int^t w(x)dx - {}_o\int^t w(x)\,\frac{T-t}{T-x}\,dx.$$

This falls short of its left hand term -- the accumulation on the left by the positive amount on the right -- converging to the accumulation as t comes close to T. This induces a convexity effect like the conditioning by factor $\frac{G(T)}{G(t)}$ but is distinct from it.

The implied $S'(t)$ is in proportion to

$$S'(t) = {}_o\int^t w(x)\,\frac{dx}{T-x}$$

Thus, when $w(t)$ is constant, $w(t) = w_o$, $S'(t)$ is $w_o \log \frac{T}{T-t}$, short of w_o until t is $\frac{e-1}{e}$ T. Then there is a catch-up region where $S'(t)$ must exceed w_o.

When factor $\frac{G(T)}{G(t)}$ is applied, as it might be, the effect is heightened, of pushing $C'(t)$ well below the relevant $S'(t)$, rescaled.

Thus, although a financing program that funds levelly in this way is useful for its financial purpose, it must be recognized as such and not mistaken for an allocation of vested funds over the pre-vesting period. For the financial manager the cost generating schedule is unimportant. It is the delay before payment of the sum that captures his attention.

F. Holding Charges

An appeal of the data of the billet cost model is (at least in principle) the description of the longevity distribution in detail. This supports -- to a degree -- the assignment of a cost to the decision to 'hold' a man in service -- a cost rate in proportion, but opposite in sign, to his cost if in fact he is not held for a billet but committed back to a pool, for acceptance or rejection again.

This is an oddity, from the accounting point of view, although it can be placed in an accounting framework in which costs (or savings) are charged at the time of retirement. It is the kind of framework that ends as a variant in the advance-deposit absurdity -- by making the average benefit $\overline{P}$, although guaranteed, an amount to be paid for each retirement.

The model on which it rests is that the decision, at time t, to 'hold' a man raises his expected ultimate retirement benefit from E(t) to E(t+h), where h is the time for which he is held and

$$E(t) = \frac{1}{G(t)} \int_t^{\infty} f(x)P(x)dx$$

Then h $E'(t)$, for h small, is the cost impact of the decision to hold.

An ultimate decision not to hold him costs $P(t)-E(t)$, where $P(t)$ is the retirement benefit at longevity t. But failure to 'hold' the man doesn't produce such a decision. He is returned to a pool, in effect, and the probability that he will be retired from the pool, in the period (t, t+h) is $hr(t)$.

Then it isn't surprising that the definition of $E(t)$ yields

$$E'(t) = r(t)\{E(t) - P(t)\}$$

just the negative of the average cost (or saving) rate for retirements in t, t+h, taking into account the present likelihood of retirement. $E'(t)$ has the same sign as $E(t) - P(t)$ -- the cost direction is positive if expectations exceed present retirement amounts; negative, if not. But factor $r(t)$ moderates the effect. When it is small, no decision at time t makes much difference. A man not held in one place will likely be held in another. When $r(t)$ is large, not holding him is likelier to lead to a retirement, with <u>its</u> effect, so that holding him can make a real cost difference if $E(t) - P(t)$ is not small.

If values $E'(t)$ are taken as use-charges, then there must be a retirement charge to assure accounting identities. With the charge for retirement set to $P(t) - (E(t) - E(0))$, cumulative charges through longevity t are just $E(0)F(t) = \overline{P}\, F(t)$ -- the average retirement cost at entry mulciplied by the proportion of retirements up through longevity t.

The 'surplus' per man still in service at longevity t is $E(t) - \overline{P}$. This is just the surplus for advance deposit funding, reduced by $\overline{P}$. Internal costs are set so that payment of $\overline{P}$ at retirement, instead of recruitment 'funds' the benefits.

What is interesting, of course, is the use-charges as answering the question of how much cost impact a single holding decision is likely to have.

G. Methods in the Billet Cost Model

Continuous analogues of methods of calculating retirement costs in the billet cost model are:

1. $$C_1'(t) = a_1\overline{P}/G^2(t)$$

where $1/a_1 = {}_0\int^\infty \frac{dt}{G(t)}$

2. $$C_2'(t) = a_2 w(t)$$

where $1/a_2 = {}_0\int^\infty \dot{G}(t)w(t)dt/\overline{P}$

and $w(t)$ = base pay in year t

3. $$C_3'(t) = a_3\overline{P}/G(t)$$

where $1/a_3$ = Maximum Career Length

4. $$C_4'(t) = \frac{a_4}{G(t)} {}_t\int^\infty f(x)\, \frac{P(x)}{x}\, dx$$

for $t \geq T$, the vesting point

and $1/a_4 = \frac{1}{P} \cdot {}_T\int^{\infty} G(t)\ {}_t\int^{\infty} f(x)\ P(x)/x\ dx$

5. $C_5'(t) = \frac{1}{G(t)}\ {}_t\int^{\infty} f(x)P(x)/x\ dx$

for all t.

Suggested originally was

6. $C_6'(t) = \frac{1}{G^2(r)}\ {}_t\int^{\infty} \frac{f(x)P(x)dx}{z(x)}$

where $z(t) = {}_o\int^{t} \frac{dx}{G(x)}$

Method 2 assigns retirement cost as a fixed fraction of base pay. Methods 4 through 6 arise from level funding considerations, with method 5 providing longevity-specific payments into a sinking fund.

IV. Application of Methods

A. Simplifications Made

The billet cost model permits the use of both discounting and the weighting of retirement costs by a distribution of grades at retirement, although this smoothing feature isn't necessarily used. In reckoning retirement principals, life tables are not used. Total life is held constant and simply reduced by one year for each year's increase in longevity -- close enough to what life tables produce anyway.

In assigning retirement costs by grade, median age in grade is utilized to look up and interpolate a grade-specific cost -- a procedure that tends to unsmooth some of the smoothing devices employed.

For the following calculations, although basic data for the AB rating has been used, the assorted devices above have been omitted, as has discounting. The cohort has been treated as progressing through the nominal grades characteristic of each longevity bracket (assigned by use of average longevity at grade attainment). In the conversion of longevity-specific to grade specific retirement costs, average populations of longevity in the nominal grade have been used.

B. Comparisons

The following ways of deriving annual retirement costs have been compared:

1. Fixed fraction of all pay (Method 2 in the BCM)
2. Level funding of expectations (Method 5 in the BCM)
3. Following the benefits schedule with interpolation by use of
   a. A level annual allocation of cost

$$S'(t) = \frac{P(T)}{T}$$

   b. Base-pay proportionate allocation of cost

$$S'(t) = \frac{w(t)P(T)}{\int_0^T w(t)dt}$$

Exhibit IV-B.1 shows longevity-specific costs obtained by each method.

Exhibit IV-B.2 shows grade-specific costs obtained by each method.

Exhibit IV-B.3 tabulates the data used in calculation.

It can be seen, moving down the list of methods, there is a tendency to reduce retirement cost at low grades and increase it at high grades.

EXHIBIT IV.B.1 ANNUALIZED RETIREMENT COST BY YEAR

YEAR	FIXED FRACTION OF PAY	WEIGHTED SINKING FUND PAYMENTS	OBLIGATIONS LEVEL INTERPOLATION	OBLIGATIONS PAY INTERPOLATION
1	1,865.27	500.34	471.76	294.44
2	1,998.84	565.51	533.20	356.62
3	2,108.52	767.45	723.61	510.52
4	2,232.32	1,644.10	1,550.18	1,157.90
5	2,501.99	2,759.00	2,601.39	2,177.82
6	2,538.55	2,852.57	2,689.62	2,284.59
7	2,743.07	2,895.13	2,729.74	2,505.47
8	2,743.07	2,938.32	2,770.47	2,542.86
9	2,855.28	2,982.16	2,811.80	2,686.37
10	2,855.28	3,646.35	3,438.05	3,284.67
11	3,193.73	5,183.49	4,887.38	5,222.83
12	3,249.83	6,539.55	6,165.97	6,704.34
13	3,418.15	7,457.79	7,031.76	8,042.43
14	3,418.15	7,632.58	7,196.56	8,230.92
15	3,524.94	7,940.79	7,487.16	8,830.82
16	3,524.94	8,541.74	8,053.79	9,499.13
17	3,834.43	9,350.57	8,816.41	11,311.61
18	4,031.71	10,235.98	9,651.25	13,019.80
19	4,145.37	11,205.24	10,565.14	14,654.47
20	4,344.82	15,846.29	15,044.58	15,044.58
21	4,758.92	12,523.76	26,235.59	26,235.59
22	5,425.32	12,625.88	39,927.72	39,927.72
23	5,715.62	13,012.47	19,790.95	19,790.95
24	5,715.62	12,863.46	3,432.80	3,432.80
25	5,715.62	12,703.26	2,669.96	2,669.96
26	5,715.62	12,686.33	1,907.11	1,907.11
27	6,269.45	12,683.07	32,189.47	32,189.47
28	6,269.45	12,693.95	418.38	418.38
29	6,269.45	12,471.06	-418.38	-418.38
30	6,269.45	12,096.77	-12,551.42	-12,551.42

EXHIBIT IV.B.2 ANNUALIZED RETIREMENT COST BY GRADE

GRADE	FIXED FRACTION OF PAY	WEIGHTED SINKING FUND PAYMENTS	OBLIGATIONS LEVEL INTERPOLATION	OBLIGATIONS PAY INTERPOLATION
2	1,865.27	500.34	471.76	294.44
3	2,045.37	651.18	613.98	421.91
4	2,333.01	2,060.40	1,942.70	1,538.74
5	2,741.06	3,037.90	2,864.36	2,632.85
6	3,367.70	7,026.21	6,624.83	7,510.83
7	3,994.43	10,208.11	9,624.97	12,894.59
8	4,504.24	14,567.18	19,352.89	19,352.89
9	5,769.86	12,728.82	17,877.59	17,877.59

EXHIBIT IV.B.3 BASIC DATA USED IN CALCULATION

YEAR	NUMBER STARTING	AVERAGE ON HAND	BASE PAY	PENSION PRINCIPAL	GRADE
1	2069.6631	1861.66185	5,153.00	0.00	2
2	1653.6606	1647.12865	5,522.00	0.00	3
3	1640.5967	1213.71340	5,825.00	0.00	3
4	786.8301	566.54810	6,167.00	0.00	4
5	346.2661	337.60935	6,912.00	0.00	4
6	328.9526	326.53490	7,013.00	0.00	5
7	324.1172	321.73485	7,578.00	0.00	5
8	319.3525	317.00525	7,578.00	0.00	5
9	314.6580	312.34525	7,888.00	0.00	5
10	310.0325	255.45135	7,888.00	0.00	5
11	200.8702	179.69820	8,823.00	0.00	6
12	158.5262	142.43550	8,978.00	0.00	6
13	126.3448	124.89815	9,443.00	0.00	6
14	123.4515	122.03795	9,443.00	0.00	6
15	120.6244	117.30120	9,738.00	0.00	6
16	113.9780	109.04845	9,738.00	0.00	6
17	104.1189	99.61575	10,593.00	0.00	7
18	95.1126	90.99895	11,138.00	0.00	7
19	86.8853	83.12750	11,452.00	0.00	7
20	79.3697	58.78120	12,003.00	217,588.00	8
21	38.1927	36.79485	13,147.00	233,158.28	8
22	35.3970	28.84145	14,988.00	260,310.60	9
23	22.2859	18.15855	15,790.00	301,633.50	9
24	14.0312	12.74385	15,790.00	322,116.00	9
25	11.4565	11.25885	15,790.00	325,668.75	9
26	11.0612	10.87040	15,790.00	328,432.00	9
27	10.6796	10.49540	17,320.00	330,405.75	9
28	10.3112	8.59285	17,320.00	363,720.00	9
29	6.8745	4.74820	17,320.00	364,153.00	9
30	2.6219	1.81095	17,320.00	363,720.00	9
31	1.0000	0.00000	0.00	350,730.00	9

SUMMARY

RETIREMENT COST	20458695.12
MAN YEARS	8431.99
COST/MAN YEAR	2426.32
COST/RECRUIT	9885.04
AVERAGE SERVICE	4.07

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APPENDIX E

NARM MANPOWER-RELATED SUPPORT COST METHODOLOGY

The cost factors described in this appendix were those used by the NARM in the development of Navy Program Factors, 31 August 1977. It is the most current set available and therefore differs slightly from the one used to develop NARM estimates in Part II of this report.

The NARM considers the following categories of support costs to be manpower-related:

- Base Operating Support
- Training
- Health Care
- Personnel Activities
  - PCS
  - Recruiting and Examining
  - Transients
  - Holding Account

The description here includes estimation of officer as well as enlisted support costs, although officer costs have otherwise been excluded from this study's empirical analysis. It also assumes that the objective is to estimate support costs for a given number of billets rather than a single (or "marginal") billet change.

Base Operating Support

This category includes manpower and O&MN costs necessary to provide

such Naval base services as laundry, mess, selected maintenance and supply room operations. Cost-estimating factors are developed by first summing the manpower and O&MN costs reported in program elements 24611N, 24612N, 24613N, 24614N, 24615N, 24617N, 24618N and 72827N, divided by three, because only one-third of B.O.S. costs are considered by the NARM to be variable. The resultant figures are then allocated across all direct unit billets in the Fleet, producing the following estimating equations:

$$BO = .0014(TB)$$

$$BE = .0178(TB)$$

$$BOM = 494.593(TB)$$

$$BOS = (BO \times OPR) + (BE \times EPR) + BOM$$

where,

BO = number of base operating officer billets required

TB = sum of officers and enlisted direct billets required

BE = number of base operating enlisted billets required

BOM = base operating O&MN costs

BOS = total base operating support cost

OPR = officer MPN factor

EPR = enlisted MPN factor

Training

The NARM considers all student costs and two-thirds of training staff and O&MN costs as variable. Data from the following program elements are used:

81114N Flight Training

81111N Recruit Traning

81112N Specialized Training

81113N Professional Training

24633N Fleet Support Training

88097N Administrative Support Training

Estimating Equations are:

$$TOM = 4.1(DE) + 286.6(TD) + 51.0(DO)$$

$$TO = .0001(DE) + .0028(TD) + .0613(DO)$$

$$TE = .1036(DE) + .0233(TD) + .0667(DO)$$

$$TRS = TOM + (TO \times OPR) + (TE \times EPR)$$

where,

TOM = training O&MN costs

DE = number of direct unit and base operating enlisted billets

TD = number of direct unit and base operating billets, officer and enlisted

DO = number of direct unit and base operating officer billets

TO = number of training staff billets required, officer

TE = number of training staff billets required, enlisted

TRS = total training cost

OPR = officer MPN factor

EPR = enlisted MPN factor

Health Care

This category includes the cost of staff and operations needed to provide medical support to direct unit manpower and to base operating manpower who in turn provide support to them. The NARM estimates this cost by summing the variable portion (2/3) of medical staff and operations costs and adding the pay of patients. The program elements used are given below:

81211N Hospitals

81212N Medical Centers

81216N Other Medical Activities

81213N Patients

Estimating equations are:

$$HOM = 414.8(TD)$$

$$HO = .0092(TD)$$

$$HE = .0182\ (TD)$$

$$HCS = HOM + (HO \times OPR) + (HE \times EPR)$$

where,

HOM = health care O&MN costs

TD = number of direct unit and base operating billets, officers and enlisted

HO = number of health care staff billets required, officer

HE = number of health care staff billets required, enlisted

HCS = total health care cost

OPR = officer MPN factor

EPR = enlisted MPN factor

Personnel Activities

This is the cost of permanent change of station (PCS), recruiting and examining activities, transients and holding account (prisoners). PCS costs are estimated for officers and enlisted by dividing the total annual PCS cost for each by the annual strength of each. These computations result in the following estimating equation:

$$PCS = 461(DE) + 1451(DO)$$

where,

PCS = total PCS cost

DE = number of direct unit and base operating enlisted billets

DO = number of direct unit and base operating officer billets

The remainder of the cost for this element is estimated by equations based on the assumption that two-thirds of recruiting and examining costs and all transient and holding account costs are variable. The program elements and estimating equations are given below:

81412N Recruiting & Examining

81411N Prisoners

81415N Transients

REOM = 88.9(DE)

REO = .0008(DE)

REE = .0071(DE)

HAO = .0012(DO)

HAE = .0118(DE)

TNO = .0584(DO)

TNE = .0433(DE)

PAS = PCS + REOM + OPR(REO + HAO + TNO) + EPR(REE + HAE + TNE)

where,

REOM = recruting and examining O&MN cost

DE = number of direct unit and base operating enlisted billets

REO = number of recruiting and examining officer billets required

REE = number of recruiting and examining enlisted billets required

HAO = holding account, officer

HAE = holding account, enlisted

TNO = number of transients, officers

TNE = number of transients, enlisted

OPR = officer MPN factor

EPR = enlisted MPN factor

PAS = total personnel activities cost

APPENDIX F

BCM CONTINUANCE RATE COMPUTATION

Given data on two inventories, taken a year apart, the obvious estimate of the continuation rate for longevity i is

$$\hat{C}_i = \frac{\text{personnel in inventory, year } y+1\text{, longevity } i+1}{\text{personnel in inventory, year } y\text{, longevity } i}$$

Inventories made available show that just this computation is characteristic of the continuation rates input to the model. These are ratios of integers close to the integers in the inventories supplied. They are only close to them, indicating that the inventories supplied for use in calculating school costs (the ones supplied) are not identical with those used to calculate continuation rates.

Because of error, transfers, and/or somewhat different counting periods, ratios $\hat{C}_i$ can exceed one. And, of course, either the numerator or denominator can be zero. The natural repair for a zero inventory is stated to be replacement of the zero by a one. The repair for $\hat{C}_i$ exceeding one is to take products $\hat{C}_i\hat{C}_{i+1}\ldots\hat{C}_{i+N-1}$ until the product is less than one. Then the N^{th} root of the product is used to estimate each contributing factor. Strings of values close to one, evidently generated by this procedure, appear regularly among continuation rate inputs. The procedure itself reappears in the coding of the model.

For the Engineering Aide rating, such strings cover all but years 1-5 and years 9-14. For Boatswain's Mates, they cover all but years 1-5, 13-15,

20-24, 27-28. The effect of such strings is, it can be seen, to "hold" personnel in the years covered by the string - arguably a correct behavior to simulate in mid-career, but not necessarily at its end. Boatswain's Mates exhibit rates of .6 and .7 in years 27 and 28, before stringing takes over. For Engineering Aides, retention rates are .92 and above from year 15 on. Thus, the BCM has built into it a tendency to retire expensive people which is entirely a numerical airtifact. This could be corrected by the introduction of "general" experience rates in years twenty-one and later.

APPENDIX G
OFFICER COSTS IN THE BCM

There are two fundamental problems which have inhibited estimation of officer costs since the BCM was first developed. They are: (1) defining a meaningful and useful set of officer "billets"; and (2) categorizing, quantifying and allocating training costs. Otherwise, cost estimation directly parallels that of enlisted manpower. These problems - and suggestions for their ameliorization - will be discussed in turn.

Categories of Officers

When billet costs for officers were last estimated by the BCM, it was for the following "designators":

Designator	Designator Code	Type Officer
OF	1100	Surface line officer
OFN	1100	Surface line officer - Nuclear trained
OB	1120	Submarine officer without sub pay
OBS	1120	Submarine officer with sub pay
OBN	1120	Submarine officer - Nuclear trained
OA	1300	Aviation officer (Pilot)
OX	Other	EDO, LDO, Supply
OXS	Other	EDO, LDO, Supply - Submarine trained

The "other" categories do not include Staff Corps officers who receive their initial training outside the Navy such as medical, dental, civil engineering, legal and chaplain. This omission would not seem to be a serious problem

insofar as potential uses of the Billet Cost Model are concerned. However, one of these designators - aviation officer - can and should be expanded. Aviation training is both varied and quite costly. A more detailed structure for classifying pilots would not only be useful, it would be a step in the direction of facilitating training cost estimation. Three possibilities suggest themselves:

- Categorization of billets by use of training (operational versus non-operational flying)
- Categorization of billets by type of aircraft (fixed versus rotary wing, attack versus support, etc.).
- Categorization of billets by type operations (VA, VF, VP, etc.).

The training requirements for the various groupings under each of these varies considerably by purpose of, and end use for, the training provided. The first alternative would separate aviation officers into three categories using existing officer billet designator codes as follows:

- <u>Code 0 - Other than operational flying</u>

  This category includes officer designator codes 1300, 1310 and 1320. These are aeronautically designated officers who have an aviation-oriented background but have no requirement to operate an aircraft or its weapon systems. These officers may participate in proficiency flying.

- <u>Code 1 - Operation flying (Frequent)</u>

  This category includes officer designator codes 1301, 1311, 1321, and 1511. These are officers required to participate as crew members to operate an aircraft or its weapons systems for specific aviation operation missions. Officers in this group are required to maintain basic flying skills and to fly frequently.

- Code 2 - Operational flying (less Frequent)

  This category includes officer designator codes 1302, 1312, 1322, 1512, 1812, 2102, and 2302. These are officers whose duties range from frequent flights to less demanding airborne duties. The missions carried out include:

  - Command and Control of aircraft
  - Mission support
  - Flight safety
  - Aircrew evaluation
  - Operational readiness
  - Maintenance programs
  - Weapons test evaluation

The levels of initial training and recurring training to maintain the required skills is apparently quite different for officers in each of these three codes. Estimates for training costs for each code will vary accordingly.

The second alternative categorization for aviation officers would be by aircraft type. There are many ways of achieving such categorizations:

- Categories by wing type
  - Fixed wing
  - Rotary wing
  - Variable wing
- Categories by mission type (aircraft and/or weapons system)
  - Attack
  - Fighter
  - Cargo/transport
  - Special electronic installation

- Search and rescue
- Patrol
- Tanker
- Reconnaissance
- Antisubmarine
- Trainer
- Other support (utility, staff, weather).

The third aviation classification would make use of standard squadron types: VA, VF, VP, VS, HS, etc.

Training Cost Estimation

There is first a need to distinguish between pre- and post-accession training. The former is clearly a start-up cost and, as such, should be included in a separate cost element and "capitalized" over all grades within a designator - similar to the proposed treatment of E-1/E-2 costs. Its estimation is conceptually straightforward; i.e., a weighted average across accession sources and costs, although obtaining reliable cost data - particularly of the marginal variety - might pose a problem.

Post-accession training is of two types, general and special. General training is more closely akin to "education" than training. It is provided through:

- Command and Staff College
- Naval Postgraduate School
- Naval War College/National Defense University
- Scholarship Programs

How these training costs should be treated in the BCM has been a largely unresolved issue. The resolution proposed here is quite simple: they should

be regarded as fixed costs and not included in any cost base from which trade-off decisions are to be made. There is no reason to expect that the level of costs incurred with this type of training would change with the addition of a pilot, a nuclear-trained submarine officer, or any of the other designators identified earler.

What remains is post-accession special training. These costs are clearly relevant to economic decisions. Examples are, in the case of aviation officers, lead-in flight familiarization and advanced flight training. Given the availability of a basic data source - which again is something of an uncertainty - the two analytic problems are developing marginal costs from the data sources, and determining how the costs should be allocated across grades. Each of these matters has been dealt with extensively throughout the report in relation to enlisted training costs, and while none of those empirical results is applicable to officer costs, the general nature of the treatment should be the same.

DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON, D.C. 20350

IN REPLY REFER TO
Ser 090/581502
9 May 1978

From: Chief of Naval Operations
To: Distribution List

Subj: Study Directive for Manpower/Hardware Life Cycle Cost Analysis Study

Ref: (a) CNO ltr Ser 96/S588959 of 4 OCT 76 (CSTAP-77)

Encl: (1) Guidance for CNO Studies and Analyses
(2) Manning Requirements for the Manpower/Hardware Life Cycle Cost Analysis Study

1. Title. Manpower/Hardware LCC Analysis Study.

2. Type. CNO Study with contractor support as authorized by reference (a).

3. Background. In its pursuit of more cost-effective weapons systems, the Department of Defense has structured a process to be followed in the acquisition of major weapons systems. A central criterion in the choice of alternative weapon systems is the total cost of the system over its economic life, i.e., its life cycle cost. This includes the cost of operating and maintaining the weapon system over its life cycle, as well as the more visible cost entailed in the procurement of the hardware. The cost of operating and maintaining the weapon system will largely be determined by the quantity and skill mix of manpower required for the successful performance of these functions over the life cycle of the system.

a. Despite the detail and depth of documentation and directive governing the Weapons System Acquisition Process (WSAP), serious problem areas regarding the establishment of Manpower, Personnel and Training Support (MP&TS) requirements, requisite skill levels, and their true costs have emerged. Major decisions within the WSAP have, in the past, been primarily based on hardware production costs while not fully considering operation and support costs. The recent dramatic increase in MP&TS costs has illuminated the fact that more attention should be given, and given earlier in the WSAP, to identification of the manpower requirements and the associated MP&TS costs of new technology weapons systems. This failure to fully identify MP&TS implications in the early stages of program development, coupled with rising manpower costs, has led to the development and production of systems which require specialized skills in excess of those available and generate life cycle costs far in excess of those estimated at the time the production decision was made. In such cases, earlier and more

rigorous consideration of the MP&TS implications in the cost/benefit analysis which supports system development might have driven concept decisions to more cost-effective alternatives. Major gains in system cost-effectiveness may be realized through the development and implementation of a process for trading off hardware and MP&TS costs for all new acquisitions beginning in the early stages of system development.

b. The HARDMAN Study, established as part of the 76/76T CSTAP, analyzed the manpower and training requirements determination functions within the WSAP. The study concluded that training and manpower planning to support emerging hardware systems occurs too late and often fails to address many issues. One of the study recommendations is that certain analytical capabilities be developed to support the conduct of tradeoff/life cycle cost analysis.

c. A true measure of the economic cost of military manpower is necessary to enable management to choose least costly alternative methods of achieving a given level of national defense. For the purposes of this study, "economic cost" is defined as "the value of resources, or the claim to future resources, as measured by market prices, given up by taxpayers to DOD for the purpose of successful performance of the Navy mission. In the HARDMAN study, for example, it was recognized that a valid measure of the economic cost of military MP&TS is necessary for rational choice among competing alternatives that have MP&TS implications.

d. The proliferation of life cycle cost models within the Navy, and of alternative philosophies and methodologies in computing MP&TS costs, have made it difficult to determine which model or methodology implied is applicable to the derivation of cost-effective manpower tradeoffs in the weapons system acquisition process. The problem in tradeoff analysis is to select those cost elements of the model relevant to the decision to be made and the amount of information available concerning that decision. Manpower LCC models such as the Billet Cost Model (BCM), the Navy Resources Model (NARM) and the NAVMAT LCC Model all contain cost elements essential to MP&TS tradeoff analysis.

4. Objectives. The objective of this study is to develop specifications for a standard MP&TS LCC model and methodology for its use. The study will analyze current Navy efforts in regard to the determination of life cycle cost elements necessary to economic analysis of MP&TS tradeoff decisions. The ultimate goal is to ensure that economic analysis is

appropriately and consistently applied in manpower/hardware tradeoff decisions throughout the WSAP. The study will analyze criteria for a manpower personnel and training support life cycle cost model useful at alternative stages of decision-making within the WSAP, consistent with available information and data. The analysis will consider the appropriate points and the level of detail at each point within the WSAP to make manpower/hardware cost tradeoffs. A major step toward acquiring the complete analytic capability for sound tradeoff analysis during the WSAP, as recommended by the HARDMAN study, will be taken with this effort.

5. Specific Guidance

a. Working within the framework of the existing weapon system acquisition process , the study group will conduct a critical examination of life cycle costing models and methodology with particular attention to MP&TS costs, and their contribution to total system economic costs over the life cycle. All stages in the development cycle of weapon system/hardware procurement will be thoroughly investigated to determine:

(1) The MP&TS cost elements necessary and available at each decision point in the WSAP that would influence the life cycle cost of the system.

(2) The level of detail and the types of data required in the cost analysis at each decision point.

(3) The "who", "when" and "where" of cost elements and the types of tradeoffs necessary at each point.

b. Beginning with the assumption that the Billet Cost Model (BCM) is the most appropriate existing cost model of military manpower from which to make manpower tradeoffs, an overall assessment of the BCM will be made to determine if it is satisfactory in its present version. Remedial action will be suggested where shortcomings are found. In particular:

(1) The theoretical methodology of the BCM will be examined, including the method of cost allocation and the present value formulae used in the model.

(2) The ability of the model to develop annual program costs will be included in the assessment and a methodology for reallocating billet costs to produce program costs will be suggested.

(3) An attempt will be made to explicitly distinguish those manpower costs which vary directly with incremental

changes in manpower from those costs which may be considered fixed over the range of small changes in manpower. The ability of the BCM to generate estimates of marginal costs will also be addressed, along with the practical problems of generating conceptually correct marginal costs. Future personnel supply limitations will be addressed along with the problem of estimating the costs of billets currently in excess demand.

c. Other existing Navy MP&TS cost models will be analyzed to highlight differences among existing MP&TS cost models and to ensure that all relevant costs are considered in the development of a manpower, personnel and training support life cycle cost model to be used in manpower/hardware tradeoff analysis.

d. The results of the above tasks will be incorporated into a final report which will include the specifications for, and a plan for the development and implementation of, a standard MP&TS life cycle cost model and underlying methodology. This will be incorporated into the overall system LCC methodology. Development and implementation responsibilities will not be a part of this study effort, but will be implied by the results and conclusions of the study.

6. Coordination and Review.

a. The study sponsor is the Deputy Chief of Naval Operations (Manpower) (OP-01C).

b. The CNO Project Officer is Mr. Paul F. Hogan (Pers-21221).

c. An advisory committee, chaired by the Assistant Deputy Chief of Naval Operations for Manpower Planning and Programming (OP-01C), will be composed of representatives of OP-02, OP-03, OP-04, OP-05, OP-090, OP-094, OP-095, OP-098,OP-099, OP-90, OP-92, OP-96. The Chief of Naval Material, the Chief of Naval Personnel, the Chief of Naval Education and Training and the President of CNA are invited to participate as members of the advisory committee. Offices and commands should submit nominations for representatives to the advisory committee within ten days from the date of this directive, to the Project Officer.

d. Study group membership requirements are listed in enclosure (2). Offices and commands designated in enclosure (2) are requested to forward to the Project Officer their nominations for the study group personnel within two weeks of the date of this directive.

e. The Director, Systems Analysis Division (OP-96), shall conduct a technical review to monitor progress and ensure the quality of the study. This effort shall include a review of working papers and reports for validity and completeness and an independent technical evaluation of the final report. Results of the review shall be promulgated to the advisory committee and the CNO Project Officer by OP-96.

f. LCDR A. W. NEWLON, Jr., USN, OP-964D2, is designated Study Monitor.

7. Reporting

a. The study plan is to be submitted to the advisory committee within four weeks of the date of this directive.

b. The Project Officer will submit quarterly progress reports to OP-96 in accordance with current directives.

c. Meetings of the advisory committee shall be called by the Chairman at appropriate times to provide guidance for the study group, to review and evaluate study progress and trends in accordance with reference (a). The Committee shall meet at least once each quarter.

d. Reports of work accomplished and study findings will be submitted to the advisory committee as tasks are completed. A staffing copy of the draft final report will be submitted to the advisory for review by 1 September 1978. The final report will be submitted to the advisory committee for approval by 1 November 1978.

William Small

WILLIAM N. SMALL
Director, Navy Program Planning

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GUIDANCE FOR CNO STUDIES AND ANALYSES

1. The assumptions which are of great importance to the outcome of the analysis shall be clearly stated in the Introduction to the report. Also, at the beginning of each chapter, annex or appendix the complete set of assumptions which are applicable shall be listed. The analysis shall determine the effects of alternative assumptions when these are critical to the study results.

2. Except for specific threat assessments explicitly described in the study directive the analysis shall identify the threat which is approved by the current DIPP, relate this to current National Intelligence Estimates, and, if needed by the study, extrapolate from these approved data to project the threat into the years beyond the published DIPP. The analysis shall examine variations in the threat, over the range of reasonable uncertainty, to measure the sensitivity of the study results to the definition of the threat; however, any departure from the approved intelligence estimates shall be clearly identified and explained in the report to distinguish between that part of the analysis which is based on the approved threat and that which rests on a variation in the approved threat. The project officer will establish liaison with NISC 00W to obtain required threat documentation or for assistance necessary to prepare a request for specific intelligence Production Requirements (DD Form 1497): OPNAVINST 3811.1 applies.

3. The analysis shall identify the key parameters (weapons systems effectiveness values, enemy tactics) which greatly affect the study results. Best estimates shall be used for the value of these parameters; in addition, greater and lesser values spanning the range of reasonable values for each parameter shall be used to determine the sensitivity of the study results to changes in these key parameters.

4. The analysis shall reflect the importance of qualitative factors such as the flexibility of systems or forces for multi-mission roles and the ease with which these forces may be inserted into or withdrawn from a confrontation.

5. A clear and concise description of each model or simulation shall be included in an appendix to the report unless such description is available in an already published document and is referenced in the report. This description is available in an already published document and is referenced in the report. This description shall explain in qualitative terms (including a logic diagram) the general methodology

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MANNING REQUIREMENTS FOR THE MANPOWER/HARDWARE LIFE CYCLE COST STUDY

1. General

a. Personnel assigned to the Study Group should have a general or specific knowledge of Life Cycle Cost Procedures, and should be familiar with the methodology for determination and programming of manpower requirements. In addition to, or in lieu of, the above, personnel should have a specific knowledge of the type and quality of cost data in their area. Each representative will be responsible for keeping his parent command informed of the progress of the study and for making his command's views known to the study project officer.

b. It is appreciated that personnel having the above qualifications will be involved in other aspects of the overall acquisition, manpower, personnel and training system. The Study Group shall operate under the direction of the CNO Project Officer and shall provide guidance and information to the study contractors. Study Group members will be required to devote approximately a 10% level of participation effort.

2. Composition

Command	Rank	Specialty
CHNAVPERS	Civ	Project Officer
OP-01 (OP-122H2)	LT	Manpower
OP-02 (OP-29)	CDR/LCDR or Civ. Eq.	Manpower/Training
OP-03 (OP-39)	CDR/LCDR or Civ. Eq.	Manpower/Training
OP-04 (OP-401)	CDR/LCDR	Integrated Logistic Support
OP-05 (OP-59)	CDR/LCDR	Manpower/Training
OP-90 (OP-901)	CDR/LCDR or Civ. Eq.	Navy Resources Model or Budget Analyst
OP-094	CDR/LCDR	Manpower/Training Requirements
OP-095	CDR/LCDR	Manpower/Training Requirements
OP-92	CDR/LCDR or Civ. Eq.	Budget Analyst
OP-96 (OP-96D)	CDR/LCDR	Cost Analyst
OP-099	CDR/LCDR	Training Resource Requirements
CHNAVMAT (MAT042) CNAVAIRSYSCOM; NAVELEXSYSCOM; NAVSEASYSCOM;	CDR/LCDR or Civ. Eq.	Life Cycle Costing

Enclosure (2) to CNO ltr Ser
090/581502 of MAY 9 [illegible]

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Command	Rank	Specialty
NAVSEC (Code 6112)	CDR/LCDR or Civ. Eq.	Design Work Study Cost Analyst
CNET	CDR/LCDR or Civ. Eq.	Training Support Analyst
CNA	Civilian	Economic Analyst

3. Reporting. All personnel shall report within two weeks from the date of this directive, when nominated, to the CNO Project Officer (Pers-21221) for indoctrination and Study Group Reporting instructions. Initial reporting can be accomplished by telephone (694-2278, Mr. Paul F. Hogan, Pers-21221).

Enclosure (2) to CNO ltr Ser
090/581502 of MAY 9 1978

Study Plan for the Manpower/Hardware Life Cycle Cost Analysis Study

Ref: (a) CNO memo ser 090/581502 of 9 May 1978

1. Tasks.

a. Task 1. Develop a conceptual overview of the Weapons System Acquisition Process (WSAP) as a series of economic decisions, identifying the key parameters and choice variables. Determine the appropriate scope of manpower/hardware tradeoff analysis within the WSAP, and the criterion(a) for choosing among alternative manpower/hardware configurations when attempting tradeoff analysis within the WSAP. The results of Task 1 will be summarized in a written report.

(1) Sub-Task 1-1. Review the results of the HARDMAN Study to provide an institutional background of the WSAP.

(2) Sub-Task 1-2. Clearly and rigorously develop the economic concept of capital/labor substitution or tradeoff possibilities as it applies to manpower/hardware tradeoffs within the WSAP.

(3) Sub-Task 1-3. Define the criterion(a) for choosing among alternative configurations of weapons systems, i.e., the criterion(a) to be used in manpower/hardware tradeoff analyses within the WSAP. Clarify the application of the concept of "economic efficiency" in conducting manpower/hardware tradeoff analysis in the WSAP.

(4) Sub-Task 1-4. Identify specific economic issues entailed in capital/labor tradeoffs, including discounting, inflation, relative price changes, the time horizon, economic life and reswitching. Resolution of these issues should be accomplished in a manner consistent with current economic theory. Specific recommendations will be part of the final report.

(5) Sub-Task 1-5. Clearly delineate the scope of manpower/hardware tradeoff analysis with the WSAP to be addressed in this analysis.

(6) Sub-Task 1-6. Briefly identify potential institutional problems in applying the conceptual economic framework of manpower/hardware tradeoff analysis to the WSAP. The areas of potential problems include data and informational limitations and scarcity of required analytical skills.

b. Task 2. Analyze the WSAP to determine the points or stage within the WSAP at which manpower/hardware tradeoffs should be made, the level of detail applicable to the tradeoff analysis at each point, the organization that should conduct the analysis at each point, and the specifications for the Manpower, Personnel and Training Support (MP&TS) life cycle cost model or system of models necessary to perform the analysis. In all cases, the criterion(a) used in making these determinations should be consistent with the overall criterion(a) defined in Sub-Task 1-3. The analysis presented in Task 2 will be presented in a written report.

(1) Sub-Task 2-1. Determine the type of MP&TS requirements information available at various stages of the WSAP. The availability of information concerning the MP&TS requirements of alternative configurations of a weapons system will dictate the level of detail at which manpower/hardware tradeoffs can be performed at each stage of the WSAP.

(2) Sub-Task 2-2. Determine the level of detail at which manpower/hardware tradeoff analysis should be conducted at each stage of the WSAP, consistent with available information as identified in Sub-Task 2-1.

(3) Sub-Task 2-3. Determine who, or which organization, should perform the tradeoff analysis at each stage of the WSAP.

(4) Sub-Task 2-4. Develop the theoretic framework for a system of MP&TS life cycle cost models to be used to conduct manpower/hardware tradeoff analysis at appropriate stages in the WSAP. Specify the manner in which the models should incorporate the state of current economic knowledge in treating discounting, inflation, etc. (as identified in Sub-Task 1-4).

(5) Sub-Task 2-5. Critically review a representative sample of existing life cycle cost models used in the development of new weapons systems to determine their efficacy in conducting manpower/hardware tradeoff analysis. The criteria for evaluating these models should be consistent with the theoretic framework identified in Sub-Task 2-4.

(6) Sub-Task 2-6. Suggest remedial action where minor problems are discovered in existing models, or outline the specifications for new models if the existing models are found to be deficient beyond amelioration at a reasonable (i.e., cheaper than starting from scratch) cost.

c. Task 3. Analyze and evaluate existing Navy MP&TS cost models to determine their ability to accurately reflect the economic cost of military manpower relevant for making resource decisions, including manpower/hardware tradeoff decisions to be made within the WSAP. The analysis completed under this task will be presented in a written report.

(1) Sub-Task 3-1. Analyze and evaluate the Navy Billet Cost Model (BCM) both in its entirety and its submodels (i.e., training, retirement costs, etc.) and its inputs. Determine the degree to which the BCM accurately reflects MP&TS costs relevant for making decisions concerning resource allocation; determine the ability of the model to reflect the average variable and marginal costs; and the ability to reflect MP&TS costs by program element.

(2) Sub-Task 3-2. Recommend remedial action where shortcomings are discovered in Sub-Task 3-1. Also, evaluate the efficacy of using the BCM as a measure of MP&TS costs to be used in manpower/hardware tradeoff analyses within the WSAP. Investigate alternative methods of aggregating BCM costs to conform to the information available at various stages in the WSAP.

(3) Sub-Task 3-3. Examine and evaluate other existing Navy models of MP&TS costs, and determine their value as a measure of manpower costs in manpower/hardware tradeoffs.

d. Task 4. Integrate the results of Tasks one through three into a coherent "blue print" which provides the specifications (or minimum requirements) for the analytic framework from which to conduct manpower/hardware tradeoff analysis during the WSAP. This framework will serve as a necessary foundation from which weapons system cost models with MP&TS implications should be based. The MP&TS cost methodology will provide the "prices" of MP&TS to be plugged into the tradeoffs of Task 2.

e. The end product of this study will be the formulation of specifications, or guidelines, for a model or set of models with which to conduct manpower/hardware life cycle cost tradeoff analysis. The study will provide the basis from which computer models can be developed, or existing models modified. The framework will provide guidance concerning the minimum analytical capabilities any such computer model must satisfy and explicit guidance for meeting these requirements. The emphasis will be on the portions of the weapons system cost models which have significant MP&TS implications. The second major product of the study will be a recommendation, supported by analysis, concerning the most appropriate model(s) of MP&TS cost estimates to be used as inputs into any manpower/hardware tradeoff model. The models recommended will be existing models of MP&TS costs (or models of portions of these costs) or these models with additional, explicit recommendations for their modification.

2. Manpower Allocation. Tasks 1 and 4 will require, primarily, the services of the Study Group and Project Officer. Contractor support has been secured via competitive bids for Tasks 2 and 3. It is anticipated that the Study Group and Project Officer will provide guidance to the contractors and monitor their progress towards accomplishing Tasks 2 and 3. The major portion of the analysis required in these tasks will be performed by the contractors. Study Group members will serve as points of contact for their respective commands to aid the contractors in the acquisition of information necessary for the success of the study. However, it is anticipated that significant amounts of resources will not be expended by either Study Group members or their parent commands in assisting the contractors.

3. Funding Allocation. Both Administrative Sciences Corporation and The Assessment Group were awarded contracts under a competitive bidding procedure in response to two separate Requests for Proposal (RFPs). The Office of Naval Research (ONR) is the contracting office. Approximate funding is $90,000 to Administrative Science Corporation for the performance of Task 3 and $60,000 to The Assessment Group for the performance of Task 2. It is recognized that these contract efforts constitute the major portion of the study and that they do not come at an insignificant expenditure of resources. It is the responsibility of the Study Group and Project Officer to monitor these contracts to ensure that the output of the contractor's efforts is worth the price.

4. Other Resources: None.

5. Task Schedule:

a. Study Directive signed: 9 May 1978.

b. Contractors on board: 1 October 1977.

c. Study Plan: 31 October 1978.

d. Task 1: 15 September - 15 November 1978.

e. Tasks 2 and 3 (simultaneous): 1 October 1977 - 31 October 1978.

f. Task 4: 15 September - 15 December 1978.

6. Specific Guidance: The purpose of this study is to define a MP&TS life cycle cost concept for conducting manpower/hardware tradeoffs for weapons systems progressing through the WSAP. As such, it will review life cycle costing inventories and procedures used in the Navy and DoD. It will identify life cycle costing parameters appropriate to the WSAP and will formulate a MP&TS life cycle costing concept for further development of life cycle cost models to be used within the WSAP for the conduct of hardware/manpower tradeoffs in weapon system design. As a minimum requirement, the following questions should be answered in the analysis:

a. What are the appropriate points within the WSAP at which to conduct manpower/hardware tradeoff analysis?

b. Who should conduct the tradeoff analysis at each point?

c. What are the minimum specifications for life cycle cost tradeoff models to be utilized at various stages of the WSAP?

d. What are the most appropriate models or measures of MP&TS costs to be used as inputs into the tradeoff model(s) which will be modified or developed in accordance with the specifications formulated by the present study?

7. Methodology. The methodology to be used in the analysis should be clear, or as clear as is desirable at this point in the study, from the statement of tests in paragraph 1. However, two salient methological points should be considered in all the tasks: (1) all analysis issued should be accomplished in a manner consistent with accepted economic theory, and (2) the results of the analysis should be presented in a manner that satisfies the pragmatic goal of providing easily implementable and understood tools with which to conduct manpower/hardware life cycle cost tradeoff analysis. The output of this study will take the form of reports summarizing the results of Tasks 1 through 3. The results of Task 1 will be summarized by the Project Officer while Tasks 2 and 3 will be summarized by the Project Officer with the assistance of the Study Group members.

8. Effectiveness Criteria. Not applicable.

9. Reports.

a. Quarterly progress reports will be submitted to OP-96 in accordance with OPNAV Instruction 5000.30 series.

b. Working papers and final report will be submitted to the Advisory Committee in accordance with Sections 1 and 5 of this Study Plan.

c. Interim briefings will be presented as required.

10. Coordination. The Study Group will coordinate with mission sponsors, program and project managers, Navy Personnel Research and Development Center, Bureau of Naval Personnel, Chief of Naval Education and Training, Naval Postgraduate School, Office of Naval Research, Center for Naval Analyses, and other organizations as appropriate.

MANPOWER/HARDWARE LIFE CYCLE COST

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CAPT R. CURRIER	CHNAVMAT
MR. J. T. WARNER	CNA
DR. F. W. SCANLAND	CNET

MANPOWER/HARDWARE LIFE CYCLE COST

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CDR J. T. EARLE	OPNAV	OP-49T
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MS. S. WHITEHEAD	OPNAV	OP-92
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